Guide for contributors to the Australian Journal of Education in Chemistry

Introduction

The Australian Journal of Education in Chemistry publishes refereed articles contributing to education in Chemistry. Suitable topics for publication in the Journal will include aspects of chemistry content, technology in teaching chemistry, innovations in teaching and learning chemistry, research in chemistry education, laboratory experiments, chemistry in everyday life, news and other relevant submissions.

Manuscripts are peer reviewed anonymously by at least two reviewers in addition to the Editors. These notes are a brief guide to contributors. Contributors should also refer to recent issues of the Journal and follow the presentation therein.

Articles

Articles should not exceed six pages in the printed form including tables illustrations and references - ca. 5000 words for a text only document. Short, concisely written articles are very welcome. Please use headings and subheadings to give your article structure.

1. We prefer to handle all submissions electronically. Our preference is for Microsoft Word files in Mac format. However, you can send files from any common Windows, DOS or Macintosh word processor.

2. On another separate page provide an abstract of 50 to 100 words;

3. All photographs should be scanned and saved in JPEG format.

4. All chemistry structures, and schemes should follow the guidelines set for ACS publications. It is preferred that Schemes, Tables etc be arranged to fit in a column 7 cm wide, although full page width will be accepted.

Reference Styles

AusJEC reference styles are based on the most recent edition of the Publication Manual of the American Psychological Association OR the Journal of Chemical Education.

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De Berg uses the strategy of a historical essay with the periodic table as its theme to engender in tertiary-level students a sense of the progress of chemistry as a human endeavour. His objective is to overcome the expressed view that technical jargon not rooted in experience and factual overload “makes it difficult to gain a sense of how concepts and theories originate, how they come to be validated and accepted, and how they connect with experience and reveal relations among seemingly disparate phenomena.” The paper includes discussion of the fallibility of any basis for periodic organisation of the elements, and the idea that a better organising principle might be a non-visualisable property of atoms such as total energy.

Bruzzone describes a simple undergraduate laboratory experiment in which titration of Fe(II) with Ce(IV) is monitored by fluorescence spectroscopy. Apart from experiencing the basics of this methodology, students can realise that because of the inner filter effect, fluorescence intensities are proportional to concentration over only a limited range of concentrations, and a correction needs to be applied.

Continuing a spectroscopy focus in this issue, Lim and Collins argue that laboratory curricula related to IR spectroscopy have not kept pace with instrumentation developments. The characteristics of modern FT-IR spectrometers allow collection of overtone transitions – described in this paper for HCl and for CO. The authors discuss the additional molecular information that can be obtained from the overtone transitions.

In a paper in the APCELL series, Shapter describes a laboratory exercise designed to demonstrate that the absorption and emission spectra of benzene do not correspond. Measurement of the “up” and “down” transitions demonstrates “in a very obvious way that what goes up does NOT necessarily come back down – at least not the same way” As usual in the APCELL series, there is an educational analysis of the exercise, including consideration of theoretical and conceptual knowledge, scientific and practical skills, and generic skills.

Many writers have discussed the barrier between chemical education research and the transfer of its findings to the classroom, lecture theatre or teaching laboratory. Coll and Taylor address the question “What does such [constructivism-based] research and thinking mean for teaching chemistry at the tertiary level?” With a preface that addresses potential problems for adopting a constructivist teaching approach at the tertiary level, the authors give a snapshot of research into students’ understandings of bonding that is a compelling argument for us to re-consider our transmissive style of tertiary teaching – although they distinguish between the demands of learning factual and conceptual content. Coll and Taylor argue that action research can provide a crucial link between the activities of research and teaching.

Finally Mitchell presents another interesting discussion in his column The Word on Chemistry.
Editorial

Many of the readers of this editorial will not have had the good fortune to attend the conference of RACI’s Division of Chemical Education held at the University of Melbourne from 30 November to 4 December entitled “Rejuvenating the teaching and learning of chemistry”. As a regular attendee of science education conferences, though not this particular biennial meeting, I take this opportunity to provide a few comments on the Melbourne meeting attended by an interesting mix of university-based and high school-based chemistry educators.

The usual conferences I attend do deal with issues of chemical education but at conferences like the National Association for Research in Science Teaching (NARST), held in the USA each year in the northern spring, or the Australasian Science Education Research Association (ASERA) annual conferences held each year in Australia or New Zealand in early July, chemistry education is one of but many topics on the program. The interested participant has to seek out these sessions by looking for topics or authors who work in chemistry education - and the focus is usually on issues related to some evaluation of teaching and learning chemistry.

So you can imagine that the title of the RACI conference suited my interests immensely - and this certainly was the case. With this issue the editors of AusJEC would like to formally acknowledge the excellent program organized by Tony Patti and Kieran Lim and the Conference Organising Committee. Every aspect of the conference worked very smoothly - a hall mark of excellent organization! I liked the structure of the program with keynote and invited presentations, workshops, poster sessions, time for socialising (always a key element of any successful meeting) and nearby Lygon Street providing a wonderful venue for restaurants and cafes.

So what impressions did I gain from this conference about chemistry education?

My main impression was that university chemists in a wide range of universities throughout Australia and New Zealand are working very hard to ensure that students are better able to engage with the concepts that they encounter in classes and laboratories and to provide a curriculum that is understandable and interesting.

Of particular note were the many presentations and poster papers allocated to improving the first year experience of chemistry students by engendering students’ level of interest in chemistry and its conceptualisation. At Curtin University, during the past year I have been involved with Mauro Mocerino and Gail Chittleborough in a project to enhance first year students’ learning and implementing online pre-laboratory exercises in order to provide a focus for student participation once they arrive at the laboratory. At the Melbourne conference, I was acutely aware that this same issue is of concern to many colleagues at universities.

The obvious issue I’d like to raise is that chemistry educators with an interest in developing approaches for improving first year chemistry need some kind of clearing house or central forum whereby these different approaches can be shared nationally. In this way, other colleagues are able to use or build on existing approaches and ideas. Of course, there are intellectual rights involved here and some fees may be in order for using other resources. Whatever this may be, I am sure that it is likely to be less than the costs of each individual university academic or group of academics developing their own special programs involving pre-labs, for example.

In an endeavour to achieve similar goals as described above, presentations and posters examined different assessment approaches, again with an emphasis on the needs of first year students. Usually the issue of assessment brought out much discussion and it was obvious among those present at the meeting that the value of formative assessment is now given much attention. Indeed there is considerable research evidence to show that effective formative assessment does make a large contribution to student outcomes and achievement.

A third issue was the recognition of the importance of tutors and ensuring that they are better prepared to teach and tutor. In keeping with this point there were paper presentations as well as a two-hour workshop. The focus on tutors’ work makes excellent sense and I can see the value of ensuring that young graduates working in chemistry departments as tutors do understand the difficulties of their less knowledgeable peers and/or undergraduates.

The emphasis on developing and enacting high quality laboratory work was most evident in the full day given to the ACELL workshops. I have been reading these experiments in the last three issues of AusJEC and can see the thoroughness with which these are produced. I am not sure how this sharing of laboratory resources came about but could something similar occur with all the developments of the first year experiences?

Chemistry colleagues are using a variety of on-line resources and software to improve the opportunities for students to learn. Of course most prominent in this forum is Roy Tasker who was the recipient of “The 2002 Chemical Education Division Medal”. Heartiest congratulations Roy! I have been aware of Roy’s work on computer animations and modelling for many years and in his medallist lecture he showed us just how far this body of excellent work has progressed.

In the final presentation of the conference Bob Bucat made an interesting and somewhat provocative challenge for the audience and I would like to finish this editorial by picking up on one of these points.

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2002 Chemical Education Conference: 
Rejuvenating the Learning and Teaching of Chemistry.

Congratulations to Tony Patti and his team for their tremendous efforts in organising and running a very enjoyable and stimulating conference in Melbourne late last year. The conference brought together over 100 chemistry educators from across Australia, New Zealand and beyond. The stimulating and varied program, the ample opportunities for discussion and networking and near by Lygon Street all contributed to a very enjoyable and fruitful conference. Those who could not attend this meeting should endeavour to come to the meeting in Hobart in February 2004. Greg Dicinoski and his team have assembled an impressive list of plenary and invited speakers and this conference promises to be every bit as good as the Melbourne meeting.

It was a special privilege to present Citations to Jenny Jones and Kieran Lim and the Chemical Education Medal to Roy Tasker. All three have had a great influence on the chemical education scene in Australia.

I first met Jenny at one of her “Captivating Chemistry” workshops at the 2000 National Convention in Canberra. Not only was the chemistry captivating, but so was her enthusiasm to promote the teaching of chemistry, particularly in primary school. Jenny’s workshops, presented over 75 times, aim to help teachers adopt a more student-centred approach in teaching chemistry by providing a range of stimulating and exciting activities that can be used in the classroom. Jenny has also designed and organised the production and distribution of the “Not all chemists wear white coats” posters and the distribution of the Nobel Prize posters for Chemistry and Physics. She was chair of the NSW Chemical Education group (1995-2000) and president of the Science Teachers Association of NSW (1992-1994). Jenny’s contribution to science/chemistry education has previously been recognised in the “Dr Alice Whitley Award” for innovation in the field of Science Education (1993), the Australian Science Teachers’ Association Distinguished Service Award (1994), the STANSW Distinguished Service Award (1998) and the RACI NSW President’s Award (2000).

Kieran is a tireless contributor to the Chemical Education Division; he established and maintains the Divisions’ website and was the program coordinator of the 2002 Chemical Education conference. He often works into the “wee small hours of the morning” and I have received many emails from Kieran that were sent well after midnight! Kieran has a keen interest in the use of technology to aid learning and has won numerous grants in this area. Kieran is an affiliate member of IUPAC and was the coordinator of “Chemical education in the information age”, a sub-theme at the 2001 IUPAC World Chemistry Congress in Brisbane and on the organising committee of the Young Scientists’ program (IUPAC 2001). These activities do not seem to impact on the quality of Kieran’s scholarly activities and outputs. He has twice won the Deakin University, Faculty of Science and Technology “Excellence in Teaching Award,” and has published many papers in chemical education journals.

Congratulations Roy, Jenny and Kieran on your well deserved Awards.

Mauro Mocerino
Roy Tasker — Division Medallist

Roy Tasker richly deserves to have been awarded the Division’s medal. His DNA material expresses itself through a combination of techno-freakishness, boundless enthusiasm, sensitivity to the challenges facing chemistry students, unlimited energy and a deep well of humanity and generosity. Through these driving forces, his contributions to chemistry education have gone beyond the borders of Australia to a truly international level.

My first close interaction with Roy came during meetings with him, Roy Sleet and Bill Chia during the VisChem project after Roy had sought and won grants from the Committee for Advancement of University Teaching totalling $80 000 in 1993 and 1994. Our common ground was the recognition that the development of useful chemical insights depends on the ability of students to visualise and model at the molecular level. If we want students to think like chemists, they need to have the same mental pictures that chemists have. In addition, they need to have an understanding of scientific language broadly in common with the meanings that chemists apply to symbols, formulas, labels and sentences.

And so many hours were spent pondering just what images chemists have of the molecular world. Non-trivial chemistry questions that engaged us in much argument included “What does a molecule of water look like?”, “How crowded are the molecules in liquid water?”, “How fast do water molecules move in liquid water?”, “How many water molecules are there, on average, between the ions in a 0.01 M aqueous sodium chloride solution?” and “What is a bubble in boiling water?”

Then there is another level of question that concerns the actuality of portrayal of systems on a computer screen to engender appropriate images for students. After all, it would not be useful to portray the movement of water molecules in the vapour phase moving across a computer screen at the same speed that they are believed to move in reality. The object is to create an appropriate perception of molecular speed in the vapour phase. Now we have questions not of chemistry, but of chemistry-related pedagogy: “Should water molecules be represented with hydrogen atoms and oxygen atoms having different colours?”, “Should collisions of water molecules in the gas phase be accompanied by a sound?”, “How can a bubble of water vapour be represented?” “How can evaporation of water at a surface be represented at the molecular level?” and “How can electron transfer in an oxidation-reduction process be represented?” These are highly philosophical questions that every chemistry teacher and every chemistry student would do well to ponder.

Roy was not only driven by consideration of these questions and possible answers, but also by a desire and a technical knowledge to manifest chosen answers through interactive teaching software. He was at the leading edge of taking computer representations beyond computerised versions of textbook and blackboard diagrams to something that tried to approach ‘reality’—where reality refers to the shared understandings of chemists. And so good were his representations (after much trial and error) that he was in much demand to demonstrate his products at important venues around the world. This has, in turn, led to offers of contracts to develop software for many leading publishers to accompany the popular textbooks of our time, and now the websites and CD supplements to many of the textbooks in common use around the world are produced by Roy and his team. Notably he has developed animations to accompany textbooks authored by Peter Atkins and Loretta Jones, and also the American Chemical Society’s ChemCom – Chemistry in the Community materials. Currently he is working on web-deliverable modules that use interactive animations and simulations to develop thinking at the molecular level for another American Chemical Society project called General Chemistry.

In case all of the above suggests that Roy’s achievements and interests are solely in the field of IT, it is worth referring to his humanity as a teacher and person. Student evaluations of Roy as a lecturer at the University of
Western Sydney always go off the scale. As a result, in 1992 he won the inaugural award for his institution’s *Award for Excellence in Tertiary Teaching*. Between 1991 and 1997, before he became overwhelmed by his software development, he presented the Youth Lecture series for each of the NSW, SA, Tasmania, Victoria and WA branches of RACI, as well as the corresponding series for the NZIC in 1993. He is regularly invited to make presentations at conferences and workshops locally, nationally and internationally, and can be relied upon to deliver an interesting and enthusiastic ‘star turn’.

Roy has worked on various committees for the Royal Australian Chemical Institute and the Australian Academy of Science. In addition, he has had considerable involvement in various programmes of public understanding of science. In recent times he has engaged in research in chemical education and is supervising at the doctoral level.

Not just work at the Conference

At the personal level, Roy is always prepared to help others of us trying to teach our subject. And, ever so beautifully, the extremes of Roy’s persona (at least in the public eye) do not go outside of the range between a smiling face and a rich body-shaking laugh. We have been lucky to have Roy in our community.

Bob Bucat
“Chemistry Education: The Elements of Change”

Royal Australian Chemical Institute - Chemical Education Division National Conference
February 5th - February 10th 2004, Hobart, Tasmania, Australia

The RACI, Chemical Education Division Conference “Chemical Education: The Elements of Change” has the primary goal of bringing together all those interested in the teaching of chemistry, from schools, colleges, universities and industries. The conference program includes a special day devoted to teachers of high school and college chemistry, and will focus on “new developments in chemistry (both for teaching and research). This day will feature presentations by leading researchers and chemical educators in Australia. A number of workshops will be conducted during the conference, and in particular a day will be devoted to the improvement of chemical teaching in the laboratory. The conference also presents the opportunity for delegates to present both oral and poster presentations, which will compliment the keynote and invited lectures.

This conference meets the requirements for a professional development activity as stated by the Teachers’ Registration Board.

Invited Keynote Speakers include:
* Prof Peter Atkins (Oxford University)
* Prof Onno de Jong (IVLOS Institute of Education, Utrecht University)
* Dr Deborah Corrigan (Monash University)
* Dr Noel Dickson (University of Sydney)

Other speakers or workshop leaders include:
* Prof Tony Hamet (Director, CSIRO Marine Laboratories)
* Prof Tony Wright, Prof Paul Haddad, Prof Scott Kable, Prof Roy Tasker, Dr Adrian George, Prof Ian Rae, Assoc Prof’s Mark Buntine/Ian Jamie, Mr Jak Denney, Assoc Prof Bob Bucat, Assoc Prof Greg Klease.

Conference Venue:
The conference will be held at the University of Tasmania, with the School of Chemistry providing the majority of the venues for the sessions. The University of Tasmania is located in the suburb of Sandy Bay that is about 2 km from the city centre and historic Salamanca Place and the docks. It is ideally situated close to public transport, entertainment venues, a host of top class restaurants and interesting places to visit. During the conference, visits to two of these places has been arranged. Due to its central location, most of the services are within easy walking distance of the University.

More photos:

Key Dates:
Registration by Friday, 31st of October 2003
Abstracts of papers by Friday, 29th of September 2003
Full Papers for inclusion in referred proceedings by 28th of November 2003

Participants will be advised by e-mail regarding whether an oral or poster presentation has been accepted.

Details of the program, registration, accommodation and tours are available on the Conference Website: <http://www.chem.utas.edu.au/ChemEdConf2004>

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Approaching a study of the periodic table from a nature of science perspective

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Abstract

An historical approach to a study of the Periodic Table which emphasises how knowledge is constructed has great value in helping students address issues related to the nature of science. A key feature of the nature of science particularly applicable to the Periodic Law is outlined and discussed with reference to the work of Dobereiner, Newlands, Mendeleeff, and recent observations by Scerri. A teaching/learning strategy used by the author with a first year tertiary chemistry class is outlined.

Introduction

Ever since the mid-nineteenth century there have been arguments put to science curriculum developers that science education should contain not only experiences in the facts of science and their confirmation but also something of the broader issues related to how science functions as a social tool in modern society; the intellectual tools it uses and the assumptions used in constructing and justifying its knowledge base; and how its intellectual heritage has interacted with other disciplines over time to change the intellectual landscape. In 1947 J.B. Conant, president of Harvard, accomplished this by using history of science episodes in his college science courses for non-science majors. However, those of us who are involved in teaching chemistry to science majors have been so often overcome by the level of content coverage required in our chemistry courses that little space or time has been available to devote to the nature of chemistry through an exposure to the history and philosophy of chemical ideas. Arnold Arons (1983) observes that efforts to cultivate scientific literacy often flounder because of an incomprehensible stream of technical jargon not rooted in experience accessible to the student and the fact that the material is presented much too rapidly and in too great a volume. This makes it difficult to gain a sense of how concepts and theories originate, how they come to be validated and accepted, and how they connect with experience and reveal relations among seemingly disparate phenomena. Yvonne Meichtry (1999) notes that the nature of science and scientific knowledge is the area most neglected by school curricula and least understood by K-12 and university students alike. Part of the reason for this has been the emphasis given in curricula to the facts of science and how these facts can be confirmed or discovered in laboratory experiences and the fact that teachers themselves have not experienced the teaching of science from a perspective which gives due consideration to matters of scientific literacy. Nature of science issues are also regarded by teachers as too abstract and too difficult to learn (Lederman, 1999). Inspite of this, curriculum bodies such as the British National Curriculum (1988), The American Association for the Advancement of Science (1993), and the New South Wales HSC Chemistry Syllabus (2000) are insisting that the nature of science be given due weight in chemistry courses.

But what is involved in a study of the nature of science and how might a study of the Periodic Table fit into the picture? Firstly, there is still significant disagreement in philosophical and educational circles about what constitutes the content and methods of science. In 1969 Herron (1969) observed the lack of a sound and precise description of the nature and structure of science and the same observation was made by Duschl (1994) twenty-five years later. Despite this difficulty McComas, Almazroa, and Clough (1998) were able to isolate fourteen consensus statements regarding the nature of science from eight international science standards documents. These are reproduced in Table 1. The authors also suggest that the fourteen statements are noncontroversial enough to be used as a basis for incorporating issues relating to the nature of science into science education curricula. Secondly, recent education reforms such as those already mentioned (NSW HSC Chemistry 2000) encourage teachers to integrate nature of science into science instruction rather than treating it as a separate topic apart from the science content. This point is emphasized by Lederman, McComas, and Matthews (1998) in their editorial for the Nature of Science issue of Science and Education when they say, “Educators must encourage textbook writers to move away from the treatment of the nature of science as a discrete topic and encourage them to infuse the history and philosophy of science throughout texts in meaningful and interesting ways”. This paper embodies this idea by showing how one of the fourteen consensus statements of the nature of science, scientific knowledge while durable has a tentative character, is exemplified in a study of the Periodic Table. The focus of the paper is the lower tertiary level chemistry classroom although some adaptations could be made to make the material applicable to the senior high school.

The chemistry context leading to the organisation of the elements—a brief summary

The concept of element as a building block of matter had been postulated in early Greek philosophy and by the fifth century BC matter was considered to consist of combinations of only four elements; earth, air, fire, and water. This idea persisted well into the time of alchemical science in the middle ages and was only really challenged from about the sixteenth and seventeenth centuries. The idea that an element was a substance that could not be broken down further by chemical means became
prominent from the time of Lavoisier in the eighteenth century and it was recognized that on this basis there were many more elements than just four as previously thought. By the beginning of the nineteenth century, then, one of the major problems that concerned chemists was the determination of the elemental composition of pure compounds. Richter (1762-1807) used quantitative methods to determine the reacting ratios of substances and introduced the term, stoichiometry, for such a process. In 1799 the French chemist Proust (1754-1826) observed that copper carbonate had the same elemental composition regardless of how it was synthesized. This was a practical proof of the law of constant proportion. Berthollet (1748-1822), however, believed that such a law was an accidental outcome of the experiment and that the elemental composition of a compound could continuously vary depending on the conditions of synthesis. However, for simple compounds the laws of constant and multiple proportions received strong experimental support due to the excellent research of the Swedish chemist Berzelius (1779-1848). In addition, the laws were consistent with Dalton’s atomic theory first proposed in 1803. According to Dalton the dense spheres of atoms of a given element were all the same size but of a different size to those of a different element and numerical values for relative atomic weights based on a mass unit of one for the hydrogen atom could be assigned to the atoms of different elements if one assumed, for example, that a compound of two elements consisted of one atom of each element. Dalton and Bezelius, however, never distinguished between the concepts of atom and molecule. This was left to Avogadro to propose in 1811 but the notion of a molecule consisting of a combination of like atoms was never accepted until the 1860 Karlsruhe conference. Thus Gay-Lussac’s law of combining volumes of 1809 combined with Avogadro’s hypothesis for the existence of molecules enabled atomic weights such as that for oxygen to be corrected.

By the middle of the nineteenth century more elements had been discovered through standard chemical methods and the new spectroscopic method of Bunsen (1811-1899). These elements were considered to consist of atoms or combinations of atoms whose relative weight could be compared to that of hydrogen. Classifying elements in terms of the relative weights of their atoms became a key research area of nineteenth century chemistry. The careful research of Stas (1813-1891) and Berzelius (1779-1848) in determining the atomic weights of the elements became crucial for systematizing the chemistry of the elements on the basis of atomic weight, a program of research which was to occupy chemists in the latter half of the nineteenth century. It cannot be underestimated how important the tedious research associated with the chemical determination of atomic weights was to the development of the Periodic Law.

**Early ideas on the organization of the elements**

The process of knowledge development in any field, and the Periodic Law is no exception, is one that builds upon the challenges of the past and the present because the challenges act as important catalysts for further knowledge generation. In 1817 thirty-five elements were known and chemists were active in assigning atomic weights to these elements based on Dalton’s Atomic Theory. Chemists were also interested in whether there was any connection between an element’s atomic weight and its chemical properties. Dobereiner observed that elements with similar chemical properties seemed to occur in TRIADS. Two examples of this grouping were lithium, sodium, and potassium as a metal triad and chlorine, bromine, and iodine as a nonmetal triad. Dobereiner observed that the atomic weight of the middle member of the triad was the average of the other two atomic weights and the properties of the middle element lay between the properties of the other two. For example, sodium’s atomic weight (23) is the average of lithium’s (7) and potassium’s (39); bromine’s atomic weight (80) is the average of chlorine’s (35.5) and iodine’s (127). The melting point of sodium (98 celsius) lies between the melting points of lithium (180 celsius) and potassium (63 celsius) and the melting point of bromine (-7 celsius) lies between the melting points of chlorine (-101 celsius) and iodine (114 celsius). These facts are still true in the modern Periodic Table but the concept of TRIAD has been superseded. By 1864 sixty-three elements had been discovered and the TRIAD law became increasingly inadequate for explaining the properties of a larger number of elements. In 1865 John Newlands observed that elements with similar chemical properties seemed to occur in OCTAVES if the elements were arranged in the order of their atomic weights. The numbers for analogous elements generally differ by 7 or some multiple of 7 as shown in Figure 1.

Organizing the elements according to triplets or octaves, known musical terms, was reminiscent of a past belief in the harmony of the universe expressed as the *music of the spheres* and of the numerical beliefs of the Pythagorean

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**Table 1** A consensus view of the nature of science objectives extracted from eight international science Standards Documents

- Scientific knowledge while durable, has a tentative character
- Scientific knowledge relies heavily, but not entirely, on observation, experimental evidence, rational arguments, and skepticism
- There is no one way to do science (therefore, there is no universal step-by-step scientific method).
- Science is an attempt to explain natural phenomena
- Laws and theories serve different roles in science, therefore students should note that theories do not become laws even with additional evidence
- People from all cultures contribute to science
- New knowledge must be reported clearly and openly
- Scientists require accurate record keeping, peer review and replicability
- Observations are theory-laden
- Scientists are creative
- The history of science reveals both an evolutionary and revolutionary character
- Science is part of social and cultural traditions
- Science and technology impact each other
- Scientific ideas are affected by their social and historical milieu
Mendeleev and Periodicity

In 1869 Mendeleev organized the elements according to their atomic weight and known chemical properties as shown in Figure 2.

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<td>Sr=87.6</td>
<td>Ba=137</td>
<td>Pb=207</td>
</tr>
<tr>
<td>?=45</td>
<td>Ce=92</td>
<td></td>
<td></td>
</tr>
<tr>
<td>?Er=56</td>
<td>La=94</td>
<td></td>
<td></td>
</tr>
<tr>
<td>?Yt=60</td>
<td>Dy=95</td>
<td></td>
<td></td>
</tr>
<tr>
<td>?In=75.6</td>
<td>Th=118</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 2: Mendeleev’s (1889) arrangement of the elements in 1869.

As the magnitude of the atomic weight increases there is a periodic change in chemical properties, apart from a small number of anomalies. Even though the modern periodic table is based on atomic number the periodicity with atomic weight still holds true for a large part of the periodic table. In fact, the order based on atomic weights is the same as the order based on atomic numbers apart from seven pairs: Ar/K; Co/Ni; Te/I; Th/Pa; U/Np; Pu/Am; Lr/Rf. This is a case of an important chemical law being originally based on a different premise (atomic weight) to that currently accepted (atomic number) but the trend according to atomic weight was sufficiently close to the trend according to atomic number to enable the basic features of the law and the elements to be established. Consider, for example, the identification of the two elements between Zn and As in Figure 2.

How did Mendeleev know that there should be two elements between zinc and arsenic and how was he able to predict the properties of these new elements? Mendeleev observed that a gap in atomic weights of the order of 1 to 3 units was typical for consecutive elements and that therefore a gap of 10 units suggested at least two elements missing in the sequence. Consider the possible properties of the analogue of silicon, ekasilicon (one element after silicon), as Mendeleev called it. Mendeleev (1897) suggested that the properties of ekasilicon, later to be called germanium, could be estimated from the properties of silicon, tin, zinc, and arsenic; that is, from elements above, below, and to the sides of it in Figure 2. The atomic weight of ekasilicon was estimated from summing the atomic weights of the four elements mentioned and dividing by four to give a kind of average. An atomic weight of around 70 was thus estimated. A similar procedure was performed with the specific gravities giving about 5.5 for the result. The properties of carbon, silicon, and tin suggested that ekasilicon (Es) would form the higher oxide, EsO₂, the lower oxide, EsO, and halides of general formula, EsX₄. The boiling points of SiCl₄ (57 celsius) and SnCl₄ (114 celsius) suggested that EsCl₄ should be a volatile liquid with a boiling point less than 100 celsius. When germanium was later discovered and its tetrachloride produced it was found to be a volatile liquid with a boiling point of about 90 celsius so the predictions proved to be correct.

The periodicity of properties based on atomic weight rather than atomic number was a good enough law to form the basis whereby some atomic weights could be corrected. Consider the case of indium which has a question mark next to it in Figure 2. The equivalent weight based on hydrogen was known to be 37.7. If indium was monovalent then one would expect its atomic weight to be 37.7, but there was no space for an element of this atomic weight in the periodic grid. If indium was divalent its atomic weight would be 75.4, close to the value shown in Figure 2. This also presents a problem because there is no space between arsenic and selenium in the grid. Trivalency would yield an atomic weight of 113.1, putting it between cadmium and arsenic in the grid. Such a space exists on the periodic grid and this position is now confirmed in that indium’s density lies between that of cadmium and tin, and the nature of its oxide is consistent with the formula, In₂O₃, with its properties intermediate between those of CdO and SnO₂.
Comparing Mendeleeff’s table of 1869 (Figure 2) with a modern periodic table reveals similarities and differences. The obvious differences are: the $s$ and $p$ block elements in their groups in Figure 2 are arranged horizontally rather than vertically; the $3d$, $4d$, and $5d$ transition elements are arranged vertically in Figure 2 rather than horizontally; no noble gases appear in Figure 2 because they had not yet been discovered; the lanthanide and actinide elements are rather incomplete in Figure 2; and there are obvious errors in some atomic weights and the group placement of the element such as in the case of uranium. Despite these differences, however, the principle of the periodicity of chemical properties has not changed even though the basis for periodicity (atomic weight to atomic number) has changed. The alkali metals, the halogens, the oxygen group, and the carbon group, for example, are clearly identified in Mendeleeff’s table. Mendeleeff’s later tables show some refinement over the 1869 table, of course, but the principle of the periodicity of chemical properties remains.

Mendeleeff probably had good reason to be confident in the role of atomic weights as the basis of periodicity given the fact that in the modern table only seven pairs of elements arranged according to atomic number do not sequence similarly when arranged according to atomic weight. In fact, Mendeleeff was so confident in the role of atomic weights that, on occasion, he was led to accept the results of experiments that were later shown to be somewhat inaccurate. The paradox is that on some occasions his firm belief in atomic weights paid off, as in the case of indium previously discussed, but on other occasions it did not pay off. In the case of tellurium and iodine shown in Figure 2, for example, Mendeleeff knew that iodine’s chemical properties put it into the halogen group even though its atomic weight (127) was less than the previous element, tellurium (128). Mendeleeff was certain that tellurium’s atomic weight was too high and that on refinement would be shown to be somewhere between 123 and 126. When the chemist, Brauner, reported an atomic weight for tellurium close to 125, Mendeleeff was ready to support this result even though it was later shown to be incorrect.

**Early and recent reflections on the completeness of the Periodic Law**

Is modern chemistry’s view of the basis of the periodicity of chemical properties now complete? When Professor W.A. Tilden delivered the Mendeleeff Memorial lecture to the Chemical Society in 1909, he challenged his audience with a most pertinent question. “Can it be truly said that the elements arranged in the order of their atomic weights show without exception periodic changes of properties?” (Tilden, 1909, p. 2094). Tilden implies that there were anomalies in the system that could not be explained because towards the end of his address he summarizes his conclusion by saying, “…the periodic law… is destined to be absorbed into a more comprehensive scheme by which obscurities and anomalies will be cleared away, the true relations of all the elements to one another revealed, and doubts as to the doctrine of evolution resolved in one sense or the other. But as with Atomic Theory itself, there is no reason to doubt that the essential features of the periodic scheme will be clearly distinguished through all time, and in association with it the name of Mendeleef will be forever preserved among the Fathers or Founders of Chemistry” (Tilden, 1909, p. 2105). Even since the modern version of the Periodic Table has been established on the basis of atomic number and electron structure, Tilden’s statement and question are still pertinent as echoed in the writings of Eric Scerri (1997, 1998). Tilden’s question could be repeated this way. Can it be truly said that the elements arranged in the order of their atomic numbers and in groups according to the pattern of their valence electron structure show without exception periodic changes of properties? The fact is, of course, as pointed out by Scerri (1997), that there are exceptions to periodicity based on electron structure. Take, for example, the ten valence electrons in the nickel, palladium, and platinum group. The valence structures are $3d^n4s^2$, $4d^{10}5s^1$, and $5d^{10}6s^1$ respectively. Scerri (1997, p. 533) comments in this respect, “Each shows a different outer-shell configuration, yet they are grouped together because of their marked chemical similarities. If it were the case that possession of a particular configuration is a sufficient condition for membership to a particular group, possession of a certain configuration would ensure that the atoms of those elements would fall into a particular group. Yet the elements, helium, beryllium, and magnesium - all of which share the property of having two outer-shell electrons - do not fall into the same group”. Scerri (1997) suggests that a better basis for periodicity probably lies in the approximate quantum mechanical calculations of nonvisualizable properties of the atom such as total energy. Reflecting on the historical development of the Periodic Law, Scerri (1997, p. 553) notes that, “Over 125 years ago Mendeleev, probably the leading discoverer of the periodic system, refused to adopt a realistic view of the system and emphasized only its classifying aspects. Exactly 100 years ago, the electron, the first subatomic component, was discovered and pointed the way for a swing back toward a realistic account of atomic physics. In due course, this led to the equally realistic electron-shell approach to the periodic system. About 30 years later, the reality of electron shells and orbitals had evaporated into the formalism of quantum mechanics, leaving behind just the mathematical utility of superimposed expressions of electronic configurations”.

What can be said about this analysis? In terms of chemical education the use of pictureable models will, I think, retain an important place in chemistry but we must help our students understand that these models are limited in what they can explain as evidenced by the anomalies mentioned. Our understanding of the Periodic Table must revolve around two separate points. Firstly, the principle upon which the elements are placed in a group of the Periodic Table relates to their chemical properties. This has been a durable feature of the Periodic Law since its inception. Secondly, the fundamental nature of matter upon which this classification takes place is still open to question, but
will probably lie in the nonpictureable entities of quantum mechanics. This aspect illustrates the tentative character of the law. The pictureable entities such as electron shells are still useful in most cases but are limited. This is an important aspect of the nature of science for students to grasp because the most common picture of science advanced in our classes is one of a system closed to any further discoveries rather than as a system still open to further enquiry. It turns out that the Periodic Law is ideal for conveying this aspect of the nature of science. But how might one incorporate these ideas in the teaching/learning strategies pertinent to a chemistry class? The next section illustrates one strategy I have used with a first year tertiary general chemistry class.

A teaching/learning strategy for incorporating the Periodic Law and the Nature of Science in the chemistry curriculum

Science teaching and learning has often been criticised for its dependence on algorithmic problem-solving and rigid laboratory tasks which do not allow for creative thinking and writing skills (Stenhouse, 1985). To rectify this situation I decided to set my first year chemistry class (19 year-olds mainly) an historical essay of 1500 words which would address how scientific knowledge was generated in the case of the Periodic Law and how the development of the Periodic Law illustrates the durable and tentative character of science. The students were asked to read the articles by Wynn and Wiggins (1997), Scerri (1997 and 1998), and Mendeleeff (undated) and to build their essay around a discussion of the following questions:

1. What are the differences between Mendeleeff’s version/s of the table and the current version and give some reasons for the differences?
2. What anomalies exist in Mendeleeff’s system?
3. How did Mendeleeff identify the element ‘ekaboron’ and the elements estimated by Mendeleeff to have atomic weights around 68 and 70?
4. What is the meaning of the term ‘periodic’ and illustrate using a particular property like melting point?
5. What do you consider to be the ‘durable’ character of the law? Give justifications.
6. What do you consider to be the ‘tentative’ character of the law? Give justifications.
7. How does the development of the Periodic Law illustrate how scientific knowledge is constructed?

Students were free to use other references in addition to those quoted and the website.

My experience is that students find writing essays on the nature of science and responding to open-ended questions rather difficult. For example, the task of identifying the durable and tentative aspects of the law proves much more challenging to the students than solving an equation for a single unknown. The fact that there is not just one correct answer in an exercise like this is an extremely valuable experience for a student who characteristically views science in dualistic terms, that is, answers to questions in science are either correct or incorrect. But the experience of writing is a creative experience and with determination and effort students find the task ultimately rewarding. The task is more easily accomplished when nature of science questions relate to specific content. The success of the exercise also depends on the quality of the reading materials. Those listed here are quite suitable for first year tertiary chemistry classes. The Periodic Law is one science area where suitable reading materials are available. This is not the case with many other scientific ideas.

Conclusion

While controversy still surrounds how one might define science and its methods, there appears to be a good case for drawing upon a consensus model of the nature of science for educational purposes and letting the development of scientific knowledge in a content area like the Periodic Law illustrate important components of this consensus model. A writing task, guided by some deliberate comments and questions, gives the student an opportunity to develop their communication skills while learning how scientific knowledge develops. This kind of teaching/learning strategy broadens the educational experience of science students and encourages them to think outside what is often regarded as the rigid boundary of a science education experience.

References

Teaching fluorescence with cerium(III)

Liliana Bruzzone

Abstract
A simple undergraduate laboratory is designed to illustrate the necessity of corrections for inner filter effects in fluorimetric analysis. The fluorometric titration of Fe(II) with Ce(IV) or vice-versa is described. The solutions are evaluated by the Ce(III) fluorescence emission. As ferrous salts are the most effective for the treatment of the iron-deficiency anemias, an analysis of a vitamin supplement containing ferrous sulfate is illustrated.

Most usual analytical methods for analyzing metals are spectrophotometry and atomic absorption spectrometry.

Spectrophotometric determinations are well established for identification and quantification of any kind of compounds. It may be performed using from very simple to rather complex instruments.

A useful method for detecting metals is atomic absorption spectroscopy but it lacks of elemental speciation as it does not indicate the oxidation state of the analyte.

As an analytical method spectrofluorimetry has the basic advantage of considerably greater sensitivity than absorption spectrophotometry.

Most of fluorometric techniques are applied to analyze organic compounds. Generally, a fluorimetric method for the detection of inorganic ions requires the combination with a chelating agent. Fluorescence in solution has been observed from inorganic ions of very few elements.

A spectrofluorimeter has become a common instrument in any analytical laboratory with a variable cost depending on the needed requirements.

Usefulness of spectrofluorimetry has been demonstrated in a vast number of analytical reports with emphasis on its great analytical sensitivity. Although the basic principles of fluorescence can be obtained in the literature (1), not always are the necessary precautions taken in when carrying out an analysis. In this paper we propose a simple laboratory experiment for demonstration of the practical aspects of fluorimetric analysis.

Two fluorimetric experiments have been adopted successfully in our undergraduate Optical Methods of Analysis course (2). Recently, we introduced a complementary experiment that uses the fluorescence of an acidic Ce(III) solution to illustrate the need of corrections for the “inner filter” effect. Fluorescence intensities are proportional to the concentration over only a limited range of absorbances. As the fluorescence instruments use 90° optical geometry, the exciting light will be absorbed in some extension at the center of the cell producing a diminution of the exciting light. The effect may decrease the intensity of the excitation at the point of observation or decrease the observed fluorescence by absorption of this fluorescence (1c).

Although previous experiments (3) have been designed to demonstrate the inner filter effect, it is the first time to our knowledge that corrections due to this effect were applied to an analysis of a real sample.

Also, the experiment helps students review the indispensable concepts of volumetric methods.

Time Requirement
The experiment may be conducted in two successive laboratory periods; the preparation of the standard solutions during the first 3-h lab period and the spectrometric measurements during the second.

Experimental Method
Equipment
Any standard commercial UV spectrophotometer with a large cell compartment may be used. A spectrofluorimeter is needed for recording fluorescence scans.

In our study, absorbance measurements were obtained with a Shimadzu UV-240 recording spectrophotometer using quartz cells of 5-cm light path. All fluorescence measurements were made in 1-cm quartz cells in a Perkin-Elmer LS-50B luminescence spectrometer.

Chemicals
The following chemicals were needed for this experiment:

- Cerous sulfate
- Ceric ammonium sulfate
- Ferrous ammonium sulfate (Mohr’s salt)
- Sulfuric acid

Solutions Preparation
A 1x10^{-2} M cerium(III) solution was prepared by weighing out the proper quantity of cerous sulfate, dissolving, and diluting to volume with 1 M sulfuric acid in a volumetric flask. This solution was standardized by iodometry following previous oxidation with persulfate.

A 1x10^{-2} M cerium(IV) solution was prepared from ceric ammonium sulfate and dissolved in 1 M sulfuric acid. The solution was standardized iodometrically.

A 1x10^{-2} M iron(II) solution was prepared from Mohr’s salt, and diluted with 1 M sulfuric acid. The solution was titrated by any standard volumetric method for iron(II).

A 1x10^{-2} M iron(III) solution was prepared from Mohr’s salt in 1 M sulfuric acid which was oxidized with hydrogen peroxide before carrying to volume. The unreacted
hydrogen peroxide was boiled away. The solution was titrated by any standard volumetric method for iron(II).

**Hazards**
Precautions must be taken when handling sulfuric acid because of its dehydrating action.

**Procedure**
The first step was to obtain the conditions for the spectrofluorimetric measurements. A $1 \times 10^{-5}$ M Ce(III) solution in 1 M sulfuric acid was used. Figure 1 shows the excitation and emission spectra of this solution.

![Spectra](image)

**Figure 1.** Fluorescence excitation and emission spectra of a $1 \times 10^{-5}$ M Ce(III) solution in 1 M sulfuric acid.

**Construction of a Calibration Curve**
Starting from the $1 \times 10^{-2}$ M cerium(III) solution successive dilutions were prepared in 1 M sulfuric acid and fluorescence intensities were measured. The excitation and emission were placed at 250 and 357 nm, respectively. Good linearity was obtained in the concentration range $1 \times 10^{-6}$ to $1 \times 10^{-4}$ M Ce(III).

**Construction of the titration curves**
To each of twelve 50-mL volumetric flasks, a constant volume of Fe(II) (or Ce(IV)) solution was added. Subsequently, to each solution, different volumes of standard solution of Ce(IV) (or Fe(II)) were added to obtain solutions covering the whole concentration range of the titration curve. Sulfuric acid (1M) was used for all dilutions. Blank solutions of Ce(IV) in 1 M sulfuric acid were prepared (without Fe(II)) when Ce(IV) was added to Fe(II) solutions.

The fluorescence emissions were measured at 357 nm with excitation at 250 nm. Absorbances were measured at 250 and 357 nm.

Absorption spectra of the Fe(II), Fe(III), Ce(III), and Ce(IV) solutions must be recorded in order to detect how they contribute to the fluorimetric measurement.

**Determination of Fe(II) in a vitamin supplement**
Iron was determined according to the given procedure for the titration curves. Two milliliters of a $1 \times 10^{-3}$ M cerium(IV) solution was added to each of 14 volumetric 50-mL volumetric flasks. After the addition of Fe(II) solution, the mixture was diluted to volume with 1M sulfuric acid. Final Fe(II) concentrations of the solutions were maintained between 0.00 and $3.50 \times 10^{-5}$ M. Each solution was duplicated.

![Graph](image)

**Figure 2.** Initial Fe(II) concentration / $10^{-6}$ mol L$^{-1}$: (a) 9.9; (b) 21.2; (c) 39.7.

An oral solution purchased in the local market was properly diluted in 1M sulfuric acid according to the product label. An aliquot of this solution was added to a 50-mL volumetric flask containing the same amount of Ce(IV) as the solutions employed to construct the calibration curve and diluted to volume. Three solutions were prepared.
Results and Discussion
Figures 2 and 3 illustrate the titration curves when different amounts of Fe(II) or Ce(IV) are titrated with Ce(IV) or Fe(II), respectively.

The inner filter effect was studied when the concentration of the reactants increased. Figure 2 shows this effect when a Ce(IV) solution was added to a constant amount of Fe(II). Before the equivalence point, when Ce(IV) is absent, contributions to the inner filter effect may be caused by the presence of the Fe(III) formed, the Fe(II) unreacted, and the Ce(III) formed during the titration. After the equivalence point, Fe(II) is absent but an excess of Ce(IV) is present. Since cerous ions were always present to some extent in Ce(IV) solutions, the fluorescence intensities of Ce(IV) solutions were measured. Thus, the obtained intensities must be corrected not only for the inner filter effect but also because of this background.

The inner filter effect was corrected applying the following equation (1c):

\[ I_{\text{corr}} \cong I_{\text{obs}} \cdot \text{antilog} \left[ \frac{(A_{\text{ex}} + A_{\text{em}})}{2} \right] \]

where \( I_{\text{obs}} \) and \( I_{\text{corr}} \) are the measured and corrected fluorescence intensities, respectively.

\( A_{\text{ex}} \) and \( A_{\text{em}} \) are 1/5 of the absorbances measured in the 5-cm light path cells.

Figure 3 shows the inner filter effect when Ce(IV) solutions are titrated with Fe(II). In this case, the value of the ordinate arrives from the Ce(III) present in the starting Ce(IV) solution.

The increase in the corrected signal improves the sensitivity of any quantification method as the slope of the calibration curve defines it.

In a typical determination of ferrous salt, a linear relationship was obtained between the fluorescence intensity and the concentration of Fe(II). The regression equation, with a correlation coefficient of 0.9997 (n=14) was

\[ Y = 52.54 + 1.30 \times 10^7 \times X \]

where \( Y \) is the fluorescence intensity and \( X \) is the concentration of Fe(II). The Fe(II) concentration of the unknown solution was \((3.00 \pm 0.05) \times 10^{-5} \) M at a 95% confidence interval. Considering the manufacturer’s specification the recovery found was 111.3%.

A relative standard deviation (RSD) of 2.8% was obtained by measuring 10 replicate samples of a \(2.23 \times 10^{-5} \) M Fe(II) solution.

The possible interference of additional active ingredients in the sample matrix was investigated. Solutions of Fe(II) and the active ingredients at the molar ratios labeled in the studied formulation were prepared and analyzed to determine the Fe(II) content. The results are shown in Table I.

![Figure 3. Initial Ce(IV) concentration / 10^6 mol L^-1: (a) 9.5; (b) 19.1; (c) 38.2.](image)

| Table I. Effect of active ingredients in the determination of Fe(II). |
|---|---|---|
| Ingredient | Molar ratio Fe(II)/Ingredient in formulation | Molar ratio Fe(II)/Ingredient in analyzed solution | Recovery %* |
| Saccharose | 1.54 | 1.53 | 99.4 |
| Sodium disulfite | 42.68 | 44.70 | 101.8 |
| Citric acid | 6.29 | 6.28 | 112.4 |

* [Fe(II)] = 2.18 × 10^-5 M, triplicate

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Some advantages of infrared overtone spectroscopy

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Abstract

In the revision of course syllabi, the updating of teaching laboratory exercises often take second place to changes in lecture content. For example, most IR experiments do not fully exploit modern FT-IR spectrometers because there is a continuing myth that IR overtone spectroscopy is not possible. This paper extends “traditional” diatomic spectroscopy experiments to include collection of overtone transitions for HCl and CO. The overtones accentuate isotope effects and vibration-rotation interaction, while minimizing some problems associated with signal saturation. The observation of both fundamental and overtone also allows the determination of the anharmonicity, well depth and bond dissociation energy.

Introduction

In the revision of course syllabi, the updating of lecture content is usually given first priority to the neglect of teaching laboratory exercises. Yet our chemistry students can spend half their “contact” time in the teaching laboratory. This has been one of the drivers for the Australian Physical Chemistry Enhanced Laboratory Learning (APCELL) Project, which has been described recently in this Journal (1). Here, we focus on infrared (IR) rotation-vibrational experiments, which mostly do not take advantage of the characteristics of modern Fourier-transform infrared (FT-IR) spectrometers.

IR rotation-vibrational experiments are a standard part of international undergraduate chemistry curricula (2, 3). These IR experiments can be used, inter alia, to determine molecular geometry (4, 5), bond lengths (6, 7), and bond order (8, 9). Existing undergraduate experiments examine fundamental vibrational transitions, because overtone transitions have been out of the range of dispersive IR spectrometers.

Eleven years ago in 1992, Keedy described an overtone spectroscopy exercise for HCN and DCN (10). Although these molecules have overtones ($2\nu = 3310$ and $2630$ cm$^{-1}$) that are well within the range of dispersive IR spectrometers (10), we suspect that the hazardous nature of HCN and its deuterated isotopomer, made Keedy’s paper remain in academic obscurity. For example, four years later in 1996, although the HCN overtone is included by Shoemaker et al., in a discussion of rotation-vibrational band shapes, the possibility of using IR overtone spectroscopy in undergraduate laboratories is not mentioned (3). In the same section, Shoemaker et al. describe the investigation of the IR combination bands of $\text{C}_2\text{H}_2$ and $\text{C}_2\text{D}_2$, but do not include overtones (3).

Also in 1992, Bozlee et al. showed (in Figure 2 of their paper (11)) that the overtone ($2\nu = 3724$ cm$^{-1}$) of NO is within the range of many dispersive IR spectrometers. Again, this observation has not been exploited in laboratory exercises, perhaps because the paper of Bozlee et al. concentrated on the theoretical analysis of the overtone, in particular on the theoretical prediction of overtone intensity (11).

In 1996, Mina-Camilde, et al. described a student laboratory exercise, which investigated the CO overtone spectrum ($2\nu = 4260$ cm$^{-1}$) using a FT-IR spectrometer (12). Yet, there persists a myth that overtone spectroscopy is not possible in the undergraduate laboratory, using common (ie teaching-grade) spectrometers. This myth has been reinforced by a number of factors, including:

- the “classic” papers on overtone laboratory exercises all used dispersive near-infrared (NIR) spectrometers to study the overtones of HCl (13–15);
- the influential text by Shoemaker et al., the 6th edition of which was published in 1996, does not include overtone experiments (3); and
- the statement by Halpern, in his 1997 text, that spectroscopy of the HCl overtone ($2\nu = \text{ca.} 5670$ cm$^{-1}$) requires NIR spectrometers (2).

Figure 1. Spectral response of the Excalibur 3000MX FT-IR spectrometer using a PermaGlow (mid-IR) source, KBr beam splitter and a DTGS detector.

In fact, common modern FT-IR spectrometers, in their standard configurations, have spectral ranges in excess of 6000–400 cm$^{-1}$, as shown in Figure 1 and Table. This paper describes how this extended range of modern FT-IR spectrometers can be utilised to enhance laboratory exercises using IR rotation-vibrational overtone spectroscopy.

Table 1: Specifications of some modern FT-IR spectrometers

<table>
<thead>
<tr>
<th>Model a</th>
<th>Specified range (wavenumber, cm$^{-1}$)</th>
<th>Resolution (cm$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jeol JIR-SPX200</td>
<td>7600-350</td>
<td>0.04</td>
</tr>
<tr>
<td>Jeol JIR-SPX60</td>
<td>7000-400</td>
<td>0.3</td>
</tr>
<tr>
<td>Oriel Instruments MIR 8000b</td>
<td>6000-350</td>
<td>0.5</td>
</tr>
<tr>
<td>Excalibur 3000MX</td>
<td>8000-375</td>
<td>0.25</td>
</tr>
<tr>
<td>Shimadzu FTIR-8400</td>
<td>7800-350</td>
<td>0.85</td>
</tr>
<tr>
<td>Shimadzu FTIR-8900</td>
<td>7800-350</td>
<td>0.5</td>
</tr>
<tr>
<td>PerkinElmer Spectrum One</td>
<td>7800-350</td>
<td>0.5</td>
</tr>
</tbody>
</table>

a Undergraduate vacation scholar.
This table is only an illustrative list, not a comprehensive list, of commercially available instruments. Inclusion, or exclusion, of any particular instrument does not imply any judgement of the suitability, or otherwise, of any FT-IR spectrometer.

The specifications for the 80007 SiC source and 80008 DTGS detector are cited for the Oriel Instruments MIR 8000. Specifications for the standard configuration are cited for all other instruments.

Experimental
The HCl used for Figure 2, and Figure 3 was generated by the action of concentrated sulfuric acid on sodium chloride (16):

$$\text{H}_2\text{SO}_4 (l) + \text{NaCl} (s) \rightarrow \text{HCl} (g) + \text{NaHSO}_4 (aq).$$

An easy extension of a HCl spectroscopy laboratory exercise would be to use deuterium chloride, which can be easily generated from D$_2$O and PCl$_5$ (17), or D$_2$O and benzoyl chloride (3), or other reagents.

The spectra shown in this paper were collected using an Excalibur 3000MX FT-IR spectrometer using a PermaGlow (mid-IR) source, KBr beam splitter and a DTGS detector. The partial pressure of HCl gas was not monitored, but the mode of of filling the 10-cm gas cell (KBr windows) would have resulted in partial pressures of approximately atmospheric pressure, either neat or slightly diluted by atmospheric air.

Discussion
The fundamental (Figure 2) and overtone (Figure 3) spectra have many qualitative similarities, but the quantitative differences make the overtone more advantageous from a teaching and learning perspective.

Firstly, the fundamental transitions of “common” gases used in IR experiments, such as HCl, CO and CO$_2$, have large absorbances, leading to signal saturation unless care is taken to decrease the partial pressure significantly below atmospheric pressure. These large absorbances can lead to distortion of the spectrum (Figure 2). On the other hand, although the overtone transitions have much lower absorbances, the sensitivity of modern detectors, coupled with computer-aided signal-averaging techniques, enables the easy measurement of the overtone (Figure 3), at, or below atmospheric pressure. The intensities of the individual peaks reflect the molecular populations corresponding to the (initial) $J$ rotational energy levels, which clearly follow the rotational Boltzmann distribution:

$$\text{Intensity of peak } (J) \propto (2J+1) \exp\{- h c \bar{B} J (J+1) / k_B T\}$$

Equation 1. Where
- $J$ is the rotational quantum number of the initial (absorbing) state,
- $h$ is Planck’s constant,
- $c$ is the speed of light,
- $\bar{B}$ is the rotational constant (the tilda indicates the use of wave number units),
- $k_B$ is Boltzmann’s constant, and
- $T$ is the temperature.

Secondly, each peak in Figure 2 and Figure 3 is split due to contributions from H-$^{35}$Cl and H-$^{37}$Cl. The isotopomeric transitions are much better resolved in the overtone (Figure 3) than in the fundamental (Figure 2). Analysis of the relative intensities of the H-$^{35}$Cl and H-$^{37}$Cl peaks in Figure 3 would enable the determination of the isotopic abundances of $^{35}$Cl and $^{37}$Cl, via the Beer-Lambert law.

![Figure 2. Typical student spectrum of hydrogen chloride showing the fundamental rotation-vibrational transition.](image1)

Thirdly, the rotation-vibrational transitions (see Figure 2 and Figure 3) show a number of closely spaced transitions, which although approximately evenly spaced, have a clear convergence to higher energy (18):

$$\Delta E_{\text{transition}} = \bar{v} v - \bar{v}_{\nu} (\nu+1) + (2\bar{B}_{\nu} - \alpha (\nu+1)) m - \alpha v m^2$$

Equation 2 where
- $\bar{v}$ is the harmonic vibrational frequency,
- $\bar{v}_{\nu}$ is the anharmonicity,
- $\nu$ is the vibrational quantum number of the final state (ie fundamental: $\nu=1$; overtone: $\nu=2$),
- $\nu_{\nu}$ refers to the pure vibrational $\nu (\nu=0)$ transition,
- $\bar{B}_{\nu}$ is the (equilibrium) rotational constant,
- $\alpha$ is the vibration-rotation interaction constant, and
- $m = J + 1$ for the R branch and $m = -J$ for the P branch.

(Note that Equation 2 includes the zeroth order rotation-vibration coupling through $\alpha$, resulting in $\alpha \nu$-dependent rotational constant, but neglects any other coupling.) These differences in spacing, $\Delta \delta = \Delta \Delta E_{\text{transition}}$, are more pronounced in the overtone (Figure 3) than in the
Finally, the observation of the overtone illustrates the difference between the harmonic and anharmonic models for vibration. Anharmonicities relax the strict $\Delta \nu = \pm 1$ selection rule which applies to harmonic vibrations. A “clean” fundamental spectrum can be obtained by reduced pressure or dilution of the HCl sample to prevent signal distortion. Using both the fundamental and overtone spectra will determine both the anharmonicity, $\alpha$, and harmonic frequency, $\nu_0$, from which the well depth, $D_e$, (and hence the bond dissociation energy, $D_0$) can be obtained: this is not otherwise possible in a conventional IR experiment.

Figure 6 shows that the overtone spectrum of carbon monoxide is also easily obtainable (12) and Bozlee has already demonstrated the same for nitric oxide (NO) (11). In Figure 6, the features at ca. 1400-1600 cm$^{-1}$, 2400 cm$^{-1}$ and 3800 cm$^{-1}$ are due to the presence of CO$_2$ and H$_2$O in the (atmospheric) “blank”. Overtone spectroscopy can also be used to probe the bonding in carbon monoxide and hence infer the direction of the CO molecular dipole (19).

Figure 6. Typical student spectrum of carbon monoxide showing both the first overtone and fundamental rotation-vibrational transitions.

Conclusion

The characteristics of modern FT-IR spectrometers (eg the “extended” range shown in Figure 1 and Table) offer opportunities, which are not available with older instruments. For the most part, undergraduate IR experiments have not kept pace with developments in instrumentation.

Figure 3 and Figure 6 show that traditional diatomic rotation-vibrational IR spectroscopy experiments are easily extended to include collection of overtone transitions. The overtone transitions (Figure 3) accentuate isotope effects and vibration-rotation interaction, while minimizing some problems associated with signal saturation. The observation of both fundamental and overtone also allows the determination of the anharmonicity, well depth and bond dissociation energy.

Acknowledgments

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Parallel Universes: Education Research and Chemistry Teaching

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Introduction

Over the past few decades there has been a huge research effort investigating aspects of the teaching and learning of science and there now are many specialist education and science education journals, dedicated conferences and symposia. Almost all such forums are aimed at education researchers. But is there any real attempt to pass on the lessons learned from such a corpus of research into the teaching community? There are some journals that purport to achieve such an aim but in our view such journals rather than producing articles about research in chemical education, report teaching tips, and/or descriptions/ assertions of ‘what I found to work in my classroom’?

In this article we attempt to address this issue for tertiary chemistry education. We will begin with an overview of science education research with an emphasis on chemical education. Our aim here is to summarize the broad themes that have come from such research. Next we look at some important issues facing tertiary chemistry educators and attempt to summarize what we think education research has to say to the tertiary chemistry educator, illustrating this message with an example from our own research. We conclude this article by presenting our views as to how tertiary chemistry educators can work together with education researchers to improve teaching and learning.

Theories of Learning in Education Research

Some of the most important ideas to arise from research in education and science education are concerned with theories of learning. There are a number of theories in the literature the most common of which is constructivism, which has it that individuals’ mentally construct knowledge in their own minds. There are also a number of variants of constructivism that place emphasis on some aspect of mental construction, for example, social-constructivism is concerned with the social interactions that occur in the learning process (see, Good, Wanderssee & St Julien, 1994). Despite the apparent differences and complexity of many theories of learning, there are some underlying ideas that are fairly commonly agreed. Most education researchers now agree that knowledge is created in the mind of the student, and that context of the learning, and prior knowledge and prior learning experiences of students are important.

If one accepts constructivist-based ideas as a basis for the acquisition of knowledge, there are important implications for teaching and learning of chemistry. We will illustrate this by looking at teaching based on constructivism.¹ There is considerable disagreement about some aspects of constructivism but agreement that an individual’s knowledge represents a mental construct. Wheatley (1991) sums up the situation:

The theory of constructivism rests on two main principles. The first principle is readily agreed to by most persons but the second causes much controversy. Principle one states that knowledge is not passively received, but is actively built up by the cognizing subject. Ideas and thoughts cannot be communicated in the sense that meaning is packaged into words and ‘sent’ to another who unpacks the meaning from the sentences. That is, much as we would like to, we cannot put ideas in students’ heads, they will and must construct their own meanings. Our attempts at communication do not result in conveying meaning but rather our expressions evoke [original italics] meaning in another, different meanings for each person. Principle two states that function of cognition is adaptive and serves the organization of the experiential world, not the discovery of ontological reality...thus we do not find truth but construct viable explanations of our experiences. (p. 10)

Few would disagree that shared meaning (to some extent) is possible, via social interaction. So, for example, although we can never know exactly what is in another individual’s mind, we can come to reasonable agreement on aspects of a bonding theory, or about a theory for the structure of the atom.

A major outcome of constructivist-based research is the alternative conceptions or misconceptions movement (Solomon, 1994; Wheatley, 1991). Interestingly, in addition to the plethora of data gathered about learners’ views of scientific concepts, this movement stimulated considerable debate about the status of learners’ intuitive ideas (Solomon, 1994). We will discuss this further later on, but suffice it to say that many education researchers now feel that labelling learner’s world-views of scientific concepts as misconceptions is unnecessarily dismissive of their views and it is now more common to refer to discrepant views as alternative conceptions or alternative frameworks rather than misconceptions (Millar, 1989).

Chemistry Teaching and New Ideas About How Students Learn

What does such research and thinking mean for teaching chemistry at the tertiary level? Acceptance of these beliefs about the nature of learning results in a significantly different view of how one would go about the teaching of chemistry (or indeed other disciplines) (Matthews, 1997a, 1995, 1998; Taber, 2000). Inherent in such an approach to learning is a shift away from the conventional teaching style based on a view of learning

¹ As we have pointed out there is no single view of constructivism, but for the sake of linguistic convenience we shall use the single term ‘constructivism’ which we take to be embodied in Wheatley’s (1991) description below.
in which science is seen as a body of knowledge that can be transmitted to the learner. From a conventional teaching point of view, students are seen to possess little, if any, prior knowledge of the concepts that they are required to learn, particularly for abstract scientific concepts (Cobern, 1993). Modern education researchers, in contrast, recognize the importance of students’ prior knowledge, and think that teachers should attempt to foster active learning, and guide learners using a process of peer- and teacher-facilitated learning (Driver, 1989a,b; Driver & Oldham, 1986; Wheatley, 1991).

To illustrate, consider a common difficulty encountered in the teaching of school and introductory tertiary level science:

For good, understandable pedagogical reasons, constructivist science educationalists...acknowledge that science as a school subject poses a formidable challenge to the teacher in maintaining the involvement of many pupils simply because the science covered at school is, almost entirely, a consensually agreed body of knowledge. There is, therefore, a limited value in children taking away from science lessons ideas that diverge radically from the accepted ones. This means that science can come to look like the transmission of a body of knowledge that cannot be challenged by the learner, and whose learning leaves little scope for the creative involvement of the learner. (Millar, 1989, p. 590)

So, instructors wanting to teach from a constructivist view of learning are faced with a dilemma, that is, the belief system of science. In other words what is the point in trying to teach by negotiation something that is so well agreed by teachers and scientists it may as well be a fact!

From a constructivist view of learning, the teacher holds an entirely different role; that of a facilitator rather than transmitter of knowledge. What teaching skills do tertiary chemistry teachers need according to this view of learning? There is some guidance provided in the literature. Hand and Vance (1995), for example, identify three new teaching tools that a modern teacher requires; negotiation, group work, and thinking on your feet. The latter skill is certainly familiar for most tertiary chemistry teachers and represents common teaching practice: the former skills are probably much less familiar.

There are a number of pitfalls in using such teaching approaches. First is the fact that the implementation of such pedagogy may prove problematic in large class sizes; second is a perceived need to cover a detailed curriculum in limited time. Elicitation of student’ prior knowledge about the topic under study, engaging in group work and so forth, all take more time than straight transmissive teaching, and this inevitably means less content is covered (Eylon & Linn, 1988). Another major concern is the link between beliefs and teaching style. The danger is that if you let students discuss and debate theories of science, it may then become problematic for teachers to debunk scientifically dubious theories. Such a view might, for example, necessitate ascribing creationism and evolution comparable status. Irzik (2000) rather extremely suggests that this might mean “we start teaching N-rays after X-rays, creationism next to Darwinian evolution, and witchcraft and voodoo magic alongside Newtonian mechanics” (p. 635). Some people think students might think the sole grounds for accepting a theory is apparent viability. In the minds of many scientists this undermines the successes of science and also undermines the role of the teacher; that of an expert instructor charged with conveying knowledge (Matthews, 1997b; Nola, 1977). The danger with such an approach is that it means teachers are seemingly obligated to treat highly verified scientific theories as if they are tentative, purely because they can never be totally ‘proven’. But as Kragh (1998) points out, even though a scientist is not divorced from his or her observations, this does not make scientific conclusions tentative, and from a practical teaching point of view, such a ‘soft’ stance may introduce some uncertainty about scientific theories or findings that is totally unjustified.

In fact, the validity of well-established scientific theories is based on a huge body of data and for any teacher to suggest that such scientific knowledge is tentative is misleading: “It is certainly not so tentative that a student can come along with a little knowledge about the subject and only one piece of evidence, and make valid decisions about it” (Harding & Hare, 2000, p. 233). Science is made from creative acts done by fallible humans, and careful, controlled procedures do not necessarily yield general conclusions, and conclusions do depend on how the evidence is interpreted. However, the more evidence supporting a conclusion (especially evidence from a variety of sources), the more confidence one can have in the results (Bianchini & Colburn, 2000). This surely is standard science that all chemistry lecturers are happy about. The ultimate arbiter of truth, as Bianchini and Colburn (2000) see it, “is consensus anchored in evidence and the accuracy of predictions based on conclusions” (p. 177). Thus, the validity of scientific conclusions is based on evidence – certainly paying attention to how it was generated – but not expressing undue concerns as to how we could ever prove something to be incontrovertibly correct (Cobern, 1993).

Following on from the argument regarding the reduction in status of scientific achievements noted above, much criticalism of new theories of learning has been centred on the status given to students’ views in the classroom, what some authors have even termed ‘children’s science’ (Bell, Osborne & Tasker, 1985). But Jenkins (2000, p. 607) asserts, “students’ ideas about natural phenomenal are too glibly described as ‘theories’.” Matthews (1997b) argues: “Why must learners construct for themselves the ideas of potential energy, mutation, linear inertia, photosynthesis, valency, and so on? Why not explain these ideas to students, and do it in such a way that they understand them?” (p. 13). This is a fair and important question. In our view, there is merit in thinking about new ways of learning. Let us illustrate why we think so with an example from our own work.

Students’ Mental Models of Chemical Bonding
The work presented here is a small part of a large study into students’ mental models for chemical bonding, an
important part of any degree program (Taber & Coll, 2002). The details of this study can be found in the published literature (see, Coll & Taylor, 2001; Coll & Treagust, 2002). Here we provide an overview of the main findings. There were two aspects of the study of relevance to our discussion here. First is the fact that the student participants held very simple views of chemical bonding. In the study the students were interviewed and asked to tell the interviewer what the bonding would be like in a series of samples shown to them (sodium chloride, steel wool, molecular iodine, etc.). The descriptions of their models were probed with follow-up questions and we also used a series of focus cards - cards that depicted model use in some way (e.g., malleability of metals, conductivity of molten salts, etc., Figure 1).

Figure 1 Example of a focus card used to probe students understanding of chemical bonding models

The study found that students from three academic levels prefer really very simple mental models for chemical bonding for all classes of substances (i.e., metallic, ionic and covalent) (Figure 2).

Figure 2 The bonding in lithium chloride according to a student participant in the study

The more advanced level students did provide a little more detail in their descriptions: probably because of their more extensive learning experiences. The findings of this study are consistent with those of other studies involving abstract chemistry concepts like atomic structure for which students showed a preference for real-looking (e.g., space-filling) models of atoms and molecular species (e.g., Harrison & Treagust, 1996; Pereira & Pestana, 1991; Taber, 2001). What is of particular interest and importance here is that even the advanced level-students, including PhD students, retained strong images of simple models like the sea of electrons and octet rule that they had encountered many years previously. This is really rather surprising given, for example, the vast differences in complexity between the octet rule and the advanced-level treatment of the molecular orbital theory, including the use of calculus and group theory.

The findings from this study suggest that despite competence in the description and use of sophisticated mental models for chemical bonding (we see this in the fact that most of these students were high academic achievers in their examinations), these students at least, prefer simple models and relate to more abstract models only in the context of tests or examinations. This is similar to previous reports in the literature for secondary school students and undergraduates (Birk & Kutz, 1999; Boo, 1998; De Posada, 1997; Harrison & Treagust, 1996; Nicoll, 2001). The fact that the students clung to these models even when they broke down is cause for concern in that their lecturers might well have expected their students to choose, or more quickly adopt, at least some of the sophisticated mental models for chemical bonding that possess more explanatory power. It should be noted that there were a number of opportunities for which the simple models were in fact inadequate (e.g., benzene).

In addition to the simple views of models found, there were a surprising number of alternative conceptions revealed in the study (Table 1).

Table 1 Students’ alternative conceptions identified in the study

| 1. Metallic bond is weak bonding |
| 2. Intramolecular covalent bonding is weak bonding |
| 3. Ionic bonding is weak bonding |
| 4. Continuous metallic or ionic lattices are molecular in nature |
| 5. The bonding in metals and ionic compounds involves intermolecular bonding |
| 6. The ionic radius of the sodium ion is greater than the chloride ion |
| 7. The ionic radius of the lithium ion is greater than the sodium ion |
| 8. Polar covalent compounds contain charged species |
| 9. Molecular iodine contains I minus ions |
| 10. The charged species in metallic lattices are nuclei rather than ions |
| 11. Metallic lattices contain neutral atoms |
| 12. Electronegativity comprises attraction for a single electron |
| 13. Molecular iodine is metallic in nature |
| 14. Ionic bonding comprises sharing of electrons |
| 15. Ionic and metallic bonding contain an element of directionality |
| 16. Ions in close-packed metal lattices possess other than eight nearest neighbours |
| 17. Metal to non-metal bonding in alloys is electrostatic in nature |
| 18. Ionic shape and packing is influenced by pressure |
| 19. Intermolecular forces are influenced by gravity |
| 20. Glass is an ionic crystalline substance |

The interview data revealed prevalent alternative conceptions for chemical bonding across academic levels of learning. In addition to some common alternative conceptions previously reported in the literature (at the secondary level at least) such as misunderstandings about intermolecular forces and molecularity of continuous lattices, the inquiry found a surprising number of alternative conceptions about even very simple ideas (in the context of tertiary chemistry education) like ion size.
and shape. Some 20 alternative conceptions were revealed, the most common being belief that continuous ionic or metallic lattices were molecular in nature, and confusion over ionic size and charge. For example, many students apparently believed molecular iodine (I₂) contained ionic size and charge. For example, many students the most common being belief that continuous ionic or and shape. Some 20 alternative conceptions were revealed, the most common being belief that continuous ionic or metallic lattices were molecular in nature, and confusion over ionic size and charge. For example, many students apparently believed molecular iodine (I₂) contained charged species and that the radius of cations such as the sodium ion were larger than those of counter-cations like the chloride ion. It is surprising that undergraduate and postgraduate students, especially given their good academic records, held such alternative conceptions. This suggests that the problems identified in the science education literature for student misunderstandings at secondary school and entry-level tertiary study are likely present even at advanced levels.

Teaching Based on Educational Research
Our own work described above and the enormous number of studies into students' understanding of abstract scientific conceptions thus suggest that conventional transmissive teaching is not without problems (Laws, 1996; Pfundt & Duit, 1997). It seems to us to be just too simplistic to ascribe misconceptions of the extent reported in the science education literature on poor teaching, academically weak students or lack of attention by students in lectures.

Kettle (2001), a highly experienced chemist and tertiary chemistry educator, argues that tertiary chemists need “better in-depth insight into student understanding, learning and difficulties” (p. 6). It is our firm belief that tertiary educators need to be aware of ideas and issues raised by research such as we have described here, since these ideas can provide clues as to why their students hold views that are in disagreement with desired teaching outcomes. We do think teachers need to be pragmatic and take a view that students alternative conceptions are important because of their significance in the learning process: not because they can be seen as equally valid alternative views of the world.

So what teaching style and approaches do we use in our classrooms, and how have new ideas from the science education literature and our own research in education about how students learn informed our teaching practice? First, we have found that you can teach factual material (i.e., consensually agreed material) readily enough by conventional transmissive means and we believe that there is little to be gained by changing this teaching approach. We can see little point in trying to elicit prior knowledge or negotiate understanding of substantial parts of tertiary chemistry, like organic functional group chemistry and descriptive inorganic chemistry (e.g., common properties of main-group elements). However, in our minds, the teaching of abstract conceptions such as atomic structure and chemical bonding is another matter entirely. This, we believe, is enhanced by a different pedagogy. For example, our tutorial classes are small, are less concerned with content and more concerned with understanding, hence

they are geared towards more interactive strategies such as those described in this paper. Specific teaching tools we have used include probing for students’ prior knowledge (e.g., using focus cards like in Figure 1 above) and probing of their understanding using tools like Prediction-Observation-Explanation (White & Gunstone, 1992), the use of concept maps (Sisovic & Bojovic, 2000), and analogues (Duit, 1991). We also have found POE also works well even in large lecture settings. Likewise, we have found success with the use of interactive group work, off-site learning experiences and more student-driven activities such as case studies of local industries (see, Coll, 1997). All of these activities challenge the student and make the chemical concepts more real and relevant to our students.

Making a Link Between Research and Teaching: A Way Forward
How then can we make the link between these parallel universes of education research and chemistry teaching? In keeping with the new theories of learning, we illustrate out views with an analogy! Imagine two parallel streams of thinking, one being research in education the other chemistry teaching. It is our contention here that they are happily (or maybe unhappily) tracking along in parallel, barely aware of each other (Figure 3). They may be travelling in the same direction (e.g., both concerned with how to improve student learning), or in opposite directions (e.g., one concerned with improving teaching and the other concerned only with research - education or chemistry). A slight deviation in tracking on either party’s part will lead to either conflict, or forging ahead together.

Figure 3 Parallel universes: Education research and chemistry teaching
It is imprudent to draw an analogy too far, but the diagram suggests that a small deviation in pathway could bring these disparate universes together. If one accepts the basis of our analogy, how might this ‘bringing together’ be achieved? We see several means by which this might be achieved. First, it is our belief that at least some of the initiative must lie with education researchers, since in our view it is more clearly their role to inform the practice of teaching and learning. This is reasonable given that such

1 Where a teacher describes an experiment or class demonstration, asks the students to predict the outcome, conducts the experiment, and then asks students to reconcile this with what actually happened - this works particularly well when the outcome is not obvious

2 Where a teacher describes an experiment or class demonstration, asks the students to predict the outcome, conducts the experiment, and then asks students to reconcile this with what actually happened - this works particularly well when the outcome is not obvious

3 Students are asked to write down all they know about a given concept and then asked to link ideas together using descriptions or linking phases
researchers purport to be engaged in research intended to improve teaching and learning. We see a real need for collaborative research efforts, and one possible way of producing some convergence between these ‘universes’ is through the employment of action research. Atweh (2002) argues that this research approach, by its very nature, offers a means of bridging the gap between research concerns and the problems of the reality of the classroom. Put simply, action research is research that is conducted by the teacher, usually (but not always) in collaboration with a researcher, in his or her classroom in order to improve learning. Of course action research is not without its problems; teachers’ time, work practices and initial training impose constraints on their involvement in research activities, and Gitlin and Gore (2000) warn that unless these factors are taken into account little progress is likely to be made in terms of improving practice.

However, if conducted effectively, action research can be extremely empowering for teachers. Teachers seeking solutions to problems identified by themselves gives them a sense of ownership of these solutions and the knowledge generated through their action research projects (Atweh, 2002).

Action research provides research findings that can be disseminated to a wider audience, while at the same time offering practitioners an engaging form of professional development intended to address problems they have identified and thus promote real change. According to Grundy (1995), action research is a more effective strategy for improving teaching and learning than most of the professional development courses which she sees more in the nature of a ‘pit stop’, where teachers are taken out of their classrooms and schools for a short time with the aim of ‘fixing up’ teaching with a bit of in-service training. In contrast, Grundy believes that action research can offer practitioners a form of continuous professional development that is more dynamic and relevant, with teachers continually reflecting on their teaching practice and devising better ways to teach. Furthermore, action research is collaborative in nature and therefore offers support to those involved along with critical reflection from a number of sources.

In applying an action research approach to the teaching and learning of bonding in chemistry, a group of teachers in collaboration with a researcher would identify a specific problem and plan how they might address this through different pedagogies (e.g., using the tools we described above). This approach would then be implemented, reflected upon and revised before being implemented again, as shown below (Figure 4).

In advocating the action research paradigm we are not suggesting it is a panacea. There are clearly no easy solutions to bridging the gap between research and practice. However, action research by its very nature would appear to offer more likelihood of impacting on practice than most other forms of educational research. Those interested in finding out more about action research should read The Action Research Planner by Kemmis and McTaggart (1988).

Research as we have described above in which we investigated students understanding of chemical bonding, has enabled us to identify alternative conceptions. We are then in a position to think about how we can change our teaching to improve learning for this important area.

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**Figure 4** The action research spiral (from Kemmis & McTaggart (1988)).

### References


**References**


Electronic Spectra of Benzene: An APCELL Experiment

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Spectroscopy is a cornerstone of modern chemistry. It is of course a window to the quantum nature of atoms and molecules. The quantum structure of matter is introduced very early and covered in some depth in most educational programs. The hands-on application of spectroscopy to probe energy levels is the ideal way to crystallise for students the quantum structure of atoms and molecules.

This experiment was developed to expose students to both the energetic structure of a molecule (the electronic structure of benzene in this case) and to the “mechanics” of spectroscopy. The electronic structure of benzene is probed through the collection of both absorption and excitation spectra in the ultraviolet region. The spectra obtained are not the same and hence the student must think about how and why peaks are obtained in a given spectrum and then must use this understanding to explain the observed difference. While the different forms of spectroscopy (absorption vs. emission for example) are often discussed in lectures, students rarely get to do a hands-on comparison of the differences in the lab. This is a particularly nice example as the method of data collection affects the result. Assignment of the spectra gives the students an understanding of the quantum levels under interrogation.

The absorption part of the experiment was originally taken from “The Theory and Applications of Ultraviolet Spectroscopy”, H. H. Jaffé and M. Orchin, Wiley (1962) pp. 134–144. The laser part of the experiment was developed in its entirety at Flinders with the help of several undergraduate students.

Educational Template

Section 1 - Summary of the Experiment

1.1 Experiment Title
Electronic Spectra of Benzene

1.2 Description of the Experiment
All the building blocks of nature, atoms and molecules, are quantum mechanical in their nature. This means they have well defined energy states in which they can exist and they cannot exist with energy in between these states. It is possible to change the system from one state to another by either adding energy to make a “jump” from a lower level to a higher one (assuming the added energy is exactly the amount of the gap) or allowing the system to “fall” from a high energy state to a lower one. This second process happens spontaneously in many cases and is used for example in Neon lights.

In this experiment, students are exposed to many rules about the transitions between states in both the “up” and “down” direction. This practical will help students understand how those transitions occur and further will demonstrate in a very obvious way that what goes up does NOT necessarily come back down—at least not the same way.

The “up” transitions are measured using standard UV spectrometer to measure an absorption spectrum of benzene. The “down” transitions are probed using a N2 laser set up where benzene is excited to an upper state and then allowed to fall back down. The fluorescence which results from these transitions is measured. Comparisons of the two spectra show the differences in transitions in the two directions.

1.3 Course Context and Students’ Required Knowledge and Skills
The basic understanding of the quantum mechanical nature of systems is generally covered in most Physical Chemistry textbooks and will be undertaken by most students in second or perhaps first year at university. The description of the lab further reinforces these ideas if the students lack some of the background. The practical also illustrates the different magnitudes of some of the transitions possible (electronic versus vibrational).

Quantum mechanical transitions are responsible for many everyday events. The most obvious examples involve the production of light for example in neon signs and lasers such as the diode laser used in CD players.

A knowledge of the quantum mechanical nature of matter is useful in this practical. The lab skills required are very common for most undergraduate students for the absorption part of the experiment. All modern instruments will be computer driven and the operational is quite simple. The laser part of the experiment can be more complicated and students will need a basic introduction to the system but then should be able to collect the data independently.

1.4 Time Required to Complete
Prior to Lab 1 hour
In Laboratory 12 hours
After Laboratory 2 hours

1.5 Other Comments
This experiment is one of the few examples of the use of a research grade piece of equipment in an undergraduate lab. Also, there are very few examples of the comparison of excitation and deactivation processes in undergraduate labs.

The two separate experiments outlined in this practical can be done as separate experiments but the learning outcomes would need to be adjusted as the comparison knowledge that comes with it would be lost.
Section 2 – Educational Analysis

Theoretical and Conceptual Knowledge:
Students are presented from a very early stage the concept of the quantum nature of atoms and molecules. One of the most obvious ways to confirm the “model” is through spectroscopy where students can “see” transitions between the various levels in the atoms or molecules. This experiment reinforces these ideas by first allowing the student to collect spectra themselves and hence watch it being collected so they see rises and falls in intensity. Of course, at the end of the collection the overall spectrum reinforces the idea that only certain transitions are possible and hence matter must be quantised.

The second idea presented in the prac is the notion that light can both be adsorbed by molecules or emitted (if the molecule is first excited). Students do both experiments and in fact are shown quite dramatically that the two processes are not always identical.

Scientific and Practical Skills:
Scientific skills include the operation of a laser and an uv-vis spectrometer. The second of these is really quite straightforward but the first requires considerable hands on work by the students in for example, tuning doubling crystals and scanning dye lasers. Analysis of the spectrum forces the students to “convert” their observations into a model of the energy states of the system. Finally, normalising is necessary as emission spectra collected over different wavelength regions have different intensities. Using the overlapping region, one spectrum of normalised intensity can be determined.

Practical skills involved include presentation of very specific scientific data in a particular and meaningful way. The understanding of much of the instrumentation is more of a scientific skill in this case given the nature of the equipment.

Generic Skills:
Generic skills from this prac do include (but are not limited to) all the skills that many current day experiments insist on: computer collection and presentation of data, report writing, spreadsheet manipulation and presentation of data (in a special way as outlined earlier), communication of the results.

This experiment does present a somewhat unique opportunity for students to develop some other generic skills. For one of the few times, students, in essence, collect the same data twice using two different methods. The uniqueness here possibly lies in the fact that the results are dramatically different. This forces the student into a problem solving situation involving the critical analysis of their data (is it right?) and the ability to apply their well-grounded knowledge to explain an unexpected result. This will help the development of skills that are at the root of life-long learning.

Learning Outcomes

**What will students learn?**

**Process**

*How will students learn it?*

**Assessment**

*How will staff know students have learnt it?*

*How will students know they have learnt it?*

<table>
<thead>
<tr>
<th>Theoretical and Conceptual Knowledge</th>
<th>Process</th>
</tr>
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<tbody>
<tr>
<td>Quantum nature of atoms/molecules</td>
<td>Record and EXPLAIN spectra</td>
</tr>
<tr>
<td>Light can be absorbed</td>
<td>Record uv-vis spectrum and explain the observation of various intensities (peaks)</td>
</tr>
<tr>
<td>Light can be emitted</td>
<td>Record the emission spectrum using laser excitation. Explain the transitions (both up and down) involved</td>
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<tr>
<th>Scientific and Practical Skills</th>
<th>Process</th>
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<tr>
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<td>Record uv-vis spectrum</td>
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<tr>
<td>Measurements of Absorption Spectra.</td>
<td></td>
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1The complete documentation for this experiment is freely available on the APCELL web site [www.apcell.org]. It includes the educational template, a set of student notes, demonstrator notes and technical notes to allow ready implementation into a new laboratory.
<table>
<thead>
<tr>
<th>Normalising Spectra</th>
<th>Student will have to overlay two spectra with appropriate scaling</th>
<th>Check of the final overall spectra Students can add together spectra with various weighting to see what differences occur.</th>
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</thead>
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<tr>
<td>Presentation of complex data</td>
<td>As above and in final report</td>
<td>Report assessment and feedback</td>
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**Generic Skills**

| Computer use | Used to collect and process data at every stage as well as present final findings | Monitoring of experimental use in addition to assessment of spectra and final reports. |
| Writing/Communication Skills | During the experiment, students explain the transitions observed verbally. In produce a report, the student must write a detailed account of a highly technical, complicated experiment and provide lucid explanations of observations. | Discussion during the lab will focus on assignment of the transitions to ensure the student has the proper understanding of the peak assignments and can express those understandings. Report marking will show if the student can, in writing, provide understandable detailed explanations. |
| Explanation of new observation | Explaining the difference in recorded spectra | Quality of explanation and the demonstration of the difference between absorption and emission. |

**Section 3 – Student Learning Experience**

3.1 **Did this experiment help you to understand the theory and concepts of the topic? If so, how, or if not, why not?**

S1: Yes. It linked two concepts (fluorescence and absorbance) and explained their relationship. It was also good in that it linked this prac with both a previous prac, and the lectures.

S2: Yes, I always find it helpful in understanding theory when I can see it occurring in front of me and I know the conditions under which the observations have been made.

3.2 **How is this experiment relevant to you in terms of your interests and goals?**

S1: Anybody who wants to become a physical chemist needs to have some understanding about how molecules behave and this prac clearly teaches you something about this.

S2: I enjoy seeing theory that I am learning or have learnt being put into practice. This experiment assisted me in grasping the theory and giving me greater confidence for the exam. It also made me more confident in retaining the knowledge as it was no longer simply a set of rules or theories to remember but could be applied to results I could visualise and explain myself.

3.3 **Did you find this experiment interesting? If so, what aspects of this experiment did you find of interesting? If not, why not?**

S1: Yes. It was a good introduction to lasers.

S2: Yes. The opportunity to use a sophisticated piece of machinery and to be able to operate it myself as well as transferring the data and being able to manipulate it to produce a meaningful graph that could be related to the theory.

3.4 **Can the experiment be completed comfortably in the allocated time? Is there time to reflect on the tasks while performing them?**

S1: Yes and Yes (while waiting for results).

S2: Yes, there was plenty of time to complete the prac and enough time to apply the theory myself. There was also ample time to consult the demonstrator and even to fool around with the equipment a little to become more comfortable with it.

3.5 **Does this experiment require teamwork and if so, in what way? Was this aspect of the experiment beneficial?**

S1: No, it was a one-on-one situation between student and demonstrator.

S2: This experiment did not really require any teamwork although comparison with others who had done the prac to assess the reproducibility of the results can be done.

3.6 **Did you have the opportunity to take responsibility for your own learning, and to be active as learners?**

S1: Yes, the prac involved questions that needed to be thought about between prac sessions and while writing the report.

S2: Once the basic methods of operation were demonstrated, I was left with a series of steps to work through, using my knowledge of the apparatus to confirm what was expected from the basic theory. There was time both during the prac and before the next session to consult textbooks and lecture notes about the relevant theory.
3.7 Does this experiment provide for the possibility of a range of student abilities and interests? If so, how?

S1: Yes, mainly because there was a demonstrator solely to help you so if you needed to ask a lot of questions you had the opportunity to do so.

S2: Yes, because the actual operation of the apparatus is not difficult, the theory can be discussed with the demonstrator in greater detail if necessary.

3.8 Did the laboratory notes, demonstrator’s guidance and any other resources help you in learning from this experiment? If so, how?

S1: The demonstrator’s guidance definitely helped as he was there to help throughout the whole prac, showing me how to use the equipment and asking me questions to make me keep thinking (but also giving hints when needed).

S2: The laboratory notes assisted in jogging my memory of the basic theory and operation of the apparatus while the demonstrator was helpful when I encountered mechanical problems (due to the trial nature of the prac rather than intrinsic problems of the apparatus) and also in asking questions to lead me towards greater understanding of the theory.

3.9 Are there any other features of this experiment that made it a particularly good or bad learning experience for you?

S1: The way the prac linked other work (another prac and the lectures) and ideas was great.

S2: It was a good learning experience in learning to work independently and gaining greater confidence with unfamiliar apparatus.

3.10 What improvements could be made to this experiment?

S1: Perhaps a little info to read before you enter the lab would be useful (it was very new when I did it though, so obviously there hadn’t been much time to organise that yet)

S2: None.

3.11 Any Other Comments

[no responses]

Continuation from page 4

With all the initiatives being developed and implemented by chemists, as I have indicated above and which was very obvious to those at the meeting, there is a need to evaluate the effectiveness of these initiatives in a rigorous manner. This is far from an easy task and educational research approaches are often needed that are too time-consuming for busy chemists. Here is an opportunity for collaboration between chemistry educators with an orientation towards the development of enhanced chemistry experiences for students and chemistry educators with an orientation towards the evaluation of these experiences. As was illustrated by a series of papers on ‘Representations in chemistry and their effect on learning’, I believe that several of us at Curtin University and the University of Western Australia are progressing in this direction. By the next RACI Chemical Education Division meeting in Hobart in February 2004 we look forward to sharing more of that research work on the evaluation of learning outcomes from different teaching/learning approaches.

DFT

Continuation from page 19


An invitation

The editors invite readers to make contributions to this Journal. As well as papers submitted for peer review, we welcome any of the following:

- Short papers on chemistry topics or concepts, from an educational perspective
- Reflective papers teaching and learning chemistry — general or specific
- Letters to the editor
- Announcements
- News about people or places
- Forthcoming events
- Books to review

DFT
The word on chemistry
Allan Mitchell

A chemistry, University of New England, Armidale NSW 2351, amitchel@metz.une.edu.au

A certain King of England is said to have once offered his kingdom for a horse, not much of a bargain, perhaps, as he was about to lose his realm and suffer a bit of pummelling by the enemy. I’m unsure if anyone took him up on his offer but I seem to remember that he won in the end. Had this not been so, the anticipated pummelling might have been his best option.

To receive a proper pummelling, one had merely to be struck repeatedly with the heavy knob on the blunt end of a sword, this accessory, then known as a pummel, was originally called a plummert because it resembled the small mass of plumbum, i.e. lead, on the end of a string by which Roman builders determined the perpendicular. Plumbers did not engage in much swordfighting, but they did pummel sheets of lead into ducting and pipes in Roman times, subsequent water contamination apparently being avoided due to the calcium carbonate deposited from the surrounding water supplies.

A Greek physician called Galen curiously dosed his patients with lead salts and became so famous that a lead sulphide mineral was later named galena in his honour. The lead which he knew was called molybdos, which the Romans reportedly pummelled into plumbum, but the molybdenum or Mo which we know was so named because the mineral galena was once called molybdaina and later confused with a similar-looking lead ore called wulfenite found to contain a previously-unknown element subsequently called molybdenum after the ore which had none.

The deposits on the inside of the lead piping would resemble the limestone which the Romans called calcis and calcis, terms which related to their term for a rock, being calc, engendering the later Anglo-Saxon ceale which became chalk and, once isolated, the metal calcium. The Romans liked rocks and built lots of things from bigger types; they also liked to gamble using a gaming rock, a calculus, and would indicate the tally of wins or losses by adding or removing a small rock or calculus, thus calculating the extent of success or failure.

“Stone me”, I hear you say. Well, this would involve the process of lapidation from the Roman lapis or stone (apparently not a rock), the ground being left strewn with stones, i.e. in a generally dilapidated condition. Add to this an Arabic term for the blue of the sky and you have the striking mineral lapis lazuli, the French taking the latter bit and saying l’azur which was later converted to azure. This word has nothing to do azo-compounds despite the sky being eighty percent nitrogen, these stem from the French azote, for life, from zoe in Greek. Should one be tempted to Anglicise the mineral term, bluestone would be obtained, this actually being copper sulfate.

Copper had been called coper and cuprum which came from the Latin term cyprium which translates as Cyprian metal which the Romans apparently obtained from mines on Cyprus. No one can say with certainty why sulfur was so named, but it was regarded as a stone around the brim, hence brimstone, of volcanoes, named for Vulcan, the Roman god of Fire, who was later employed to heat up and vulcanise mixtures of sulfur and sticky rubber latex, causing this to rapidly crosslink and cure.

While calcic deposits would stick to Roman pipes, the Greeks had found the stony region of Thessaly (now in modern Turkey) to be quite attractive. The region (and city) of Magnesia was rich in minerals, one of which, magnesolithos (or stone of magnesia), actually the iron oxide magnetite, invoked significant scientific curiosity because it had properties later described as magnetic. The region also yielded white magnesia (magnesia alba) or magnesium carbonate, and black magnesia (magnesia negra) or manganese dioxide. Magnesium’s derivation is obvious, but manganese started as manganum and was later changed to prevent confusion.

The sense of locating minerals in mines has rather disputed beginnings, an Old Celtic term, meini, leading onto mwyn in Welsh and meinn in Irish, and referring to an ore or its metal, while, in Latin, things mineralis described aspects of a minaria, the matrix in which metals and gems grew. As for metals, Greeks out exploring had to metalloin while Romans dug useful stuff out of a metallum. An ore, though, filters through to us via or, ar and er, and similar, from a Latin aes, aeries and Sanskrit ayas, both referring to crude copper or bronze. The aes term became synonymous with money and value, an aistimare providing English speakers with estimates and, via a reduced French esmer, aims. In time, emperors liked to stamp their likenesses onto coins made from aeries, profiles being superceded at the end of each reign and engendering the timely usage of the term aera, now known as an era.

Metallic applications to human speech are rife – one can plumb new depths, be as bold as brass, as good as gold or as hard as steel, and opinions can be cast in bronze. As for brass and bronze, origins are disputed, brass could reflect an Old Swedish flam or brasa, while looking somewhat brunctus or brownish from burning, the German brunst gave us bronze. I could, of course, go on but then I may be accused of brazenly swinging the lead.
EXCELLENT RESOURCES FOR SENIOR SECONDARY SCIENCE COURSES AVAILABLE WITHIN AUSTRALIA

The Chemical Education Group of the RACI (SA Branch) has exclusive distribution arrangements within Australia for a number of high quality science magazines, predominantly in Chemistry. The magazines are available on a subscription basis. A few selected books and CD ROMs are also available for purchase.

All of the materials are suitable for teacher and student use.
The resources available are:

Magazines

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<tr>
<td>ChemMatters</td>
<td>Published 4 times per year by the American Chemical Society</td>
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<tr>
<td>Chemistry Review</td>
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<tr>
<td>CHEM 13 NEWS</td>
<td>Published 9 times per year by the Chemistry Department, University of Waterloo (Canada)</td>
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<tr>
<td>Physics Review</td>
<td>Published 4 times per year for the Physics, Electronics and Education Departments, University of York (UK)</td>
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Biological Sciences

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<td>Review</td>
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CDROMs

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<tr>
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Books

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<tr>
<td>Ben Selinger</td>
<td>Chemistry in the Marketplace (5th Ed.)</td>
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<tr>
<td>Ben Selinger</td>
<td>Why the Watermelon won’t Ripen in your Armpit</td>
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Call For Nominations:
The Chemical Education Division Medal and Citation(s)

Nominations are now being sought for the Chemical Education Division Medal and Citations.

The Medal is the premier award of the Chemical Education Division of the Royal Australian Chemical Institute and may be awarded to any member of the RACI for whom excellence in chemical education can be demonstrated. Nominations will be considered on the basis of the overall contribution to chemical education in Australia in the previous 10 year period and contribution to chemical education by way of research and teaching and/or promotion of chemistry. One medal may be awarded at each National Meeting of the Division, the next being the Chemical Education National Conference in Hobart in February 2004. The recipient shall be invited to present a paper to the National Meeting at which the award is made.

The Citation(s) shall be awarded in recognition of a significant contribution to Chemical Education and up to three citations may be awarded in each calendar year. Where possible the citations shall be presented at a National Meeting of the Division. The recipient(s) may be invited to present a paper either to a National Meeting of the Division or, if that is not possible, to a specially designated meeting in the State or Territory of residence of the recipient.

Submissions may be made by self-nomination, by nomination by two members of the Chemical Education Division, or by invitation of the Standing Committee of the Division. Nominees for the Medal must be RACI members, while those for the Citation need not be.

Full details of the application process and conditions are given on the Division’s webpage at: http://www.deakin.edu.au/fac_st/bcs/RACI_ChemEd/

Nominations close on Friday 31 October 2003 and should be addressed to the Secretary, Janette Head.
Department of Chemistry, University of Western Australia, 35 Stirling Highway, Crawley WA 6009, Australia. Email: jhead@chem.uwa.edu.au, Fax: (+61)(8) 9380 3432.