

The Chemistry of the Platinum Metals

A REVIEW OF THE SEVENTH INTERNATIONAL CONFERENCE

By C. F. J. Barnard

Johnson Matthey Technology Centre

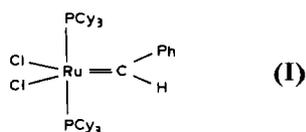
and W. Weston

Chemicals Development, Johnson Matthey, Royston

The latest in this well-established series of conferences on the chemistry of the platinum group metals, organised by the Dalton Division of the Royal Society of Chemistry, was held at the University of Nottingham, U.K., from 25th to 30th July, 1999. Approximately 250 delegates from around the world heard 46 plenary and invited lectures and viewed 120 posters illustrating a few of the many topics being researched in the platinum metals.

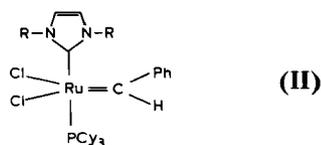
After a welcome by Professor Martin Schröder of the University of Nottingham, the introductory plenary lecture was given by Professor B. F. G. Johnson (University of Cambridge, U.K.) who described the background and current state of nanoparticle research within his group. The properties of nanoparticles produced can be altered by surface modification, achieving control of their binding to surfaces and offering possibilities for their use as single electron devices in microelectronics.

The ruthenium ring opening metathesis polymerisation (ROMP) catalysts (**I**) described by



Professor R. H. Grubbs (California Institute of Technology, U.S.A.) are tolerant of a wide range of functional groups, which also leads to application in ring closing metathesis reactions of interest to the pharmaceutical industry. However, these catalysts react more slowly than early transition metal catalysts, such as those based on molybdenum. Since activation of the ruthenium catalyst involves phosphine dissociation, complexes where one phosphine ligand has been replaced with an N-donor ligand were

prepared – imidazoline-2-ylidenes being suitable ligands – and these complexes (**II**) have



reaction rates comparable to those of molybdenum ROMP catalysts. Grubbs also described work on olefin polymerisation aimed at developing catalysts' tolerance of a range of functional groups.

Theoretical studies of olefin polymerisation were described by Professor T. Ziegler (University of Calgary, Canada) who had made calculations using approximate density function theory (DFT) to look at the energetics of termination, isomerisation and insertion as competing processes for the reaction intermediate. The introduction of increasing steric bulk in diimine ligands on palladium or nickel (Brookhart catalysts) makes insertion more favourable than termination, thus increasing the molecular weight of the polymer obtained. These calculations are now being extended to copolymers. Professor O. Eisenstein (Université de Montpellier, France) described thermodynamic calculations for ruthenium olefin complexes and relative energetics of isomerisation and insertion reactions.

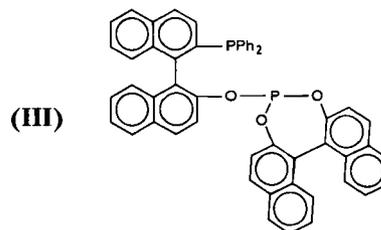
B. Milani (Università di Trieste, Italy) reported studies of CO/styrene copolymerisation using Pd complexes containing dinitrogen donor ligands, in particular phenanthroline complexes [Pd(R-phen)₂][PF₆]₂. Bulky substituents (such as isopropyl) at the 3-position of the phenanthroline ligands allow high molecular weight polymers (M_w up to 134,000) to be obtained. The complexes have *cis* geometry and steric interactions produce distortion of the palladium co-ordination away from square planar. Dissociation of one R-phen ligand allows the catalytic cycle to proceed.

Catalyst Separation for Homogeneous Catalysis

One of the major difficulties to be overcome for industrial application of homogeneous catalysis is the separation of the product from the catalyst. Professor D. J. Cole-Hamilton (University of St. Andrews, U.K.) described efforts to resolve this for reactions carried out in supercritical carbon dioxide (scCO₂). Performing reactions in supercritical fluids allows rapid diffusion and hence potentially high reaction rates. However, the solubility characteristics of scCO₂ are not suited to PPh₃ complexes as catalysts, and for high-boiling products, catalyst/product separation remains to be addressed. For hydroformylation, studies using PEt₃ and then P(OPh)₃ as ligands showed that they can produce acceptable rates, and for the latter an acceptable selectivity (*n/i* ratio), while the catalyst is essentially insoluble in high boiling aldehydes allowing easy separation.

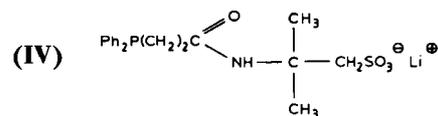
An alternative approach to catalyst separation by immobilisation of phosphine ligands was discussed by C. Bianchini (ISSECC-CNR, Florence, Italy). Procedures for anchoring the ligands to silica either by covalent linkages Si-O-Si or by association by hydrogen bonding SO₃⁻... HO-Si were described. In the latter case, solvents must be chosen carefully to avoid leaching of the catalyst from the surface. In comparison with the corresponding homogeneous catalysts, supported catalysts were shown to be potentially more selective in asymmetric hydrogenation.

K. Nozaki (Kyoto University, Japan) described another method of incorporating a ligand into a polymer by modification with a vinyl group, which allows copolymerisation with divinylbenzene and ethylstyrene. Reaction with a suitable metal precursor yields the polymer-supported catalyst. For styrene hydroformylation, good enantioselectivity can be achieved with rhodium catalysts containing the Binaphos ligand (III). Comparisons between the supported



and homogeneous catalysts indicated only a slight reduction in regio- and enantioselectivity (polymer catalyst *n/i* ratio *ca.* 1:5, ee 89 per cent).

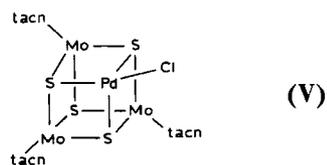
The development of systems for the carbonylation of benzyl halides using water soluble phosphines was discussed by Professor A. M. Trzeciak (University of Wroclaw, Poland). Using a sulfonated phosphine PNS (IV) the product



can be separated from the catalyst into an organic phase by weak acid extraction. A typical catalytic system is obtained by mixing the ligand with [PdCl₂(COD)], water, toluene and a base such as triethylamine under CO (10 bar). In alcohol/water mixtures a good yield of the ester can be obtained. Mechanistic studies were undertaken to confirm the reaction intermediates, such as [PdBr(PhCH₂)(PNS)₂], and to study its reaction with the alcohol.

Professor M. Hidai (University of Tokyo, Japan) reported that transition metal sulfido clusters with cubane-type structures can be prepared by a variety of routes. The compounds can have mixed metal content M₂M'₂S₄ and

$M_3M'S_4$, for example Mo_3PdS_4 , species where Pd occupies one vertex (V). Co-ordination of



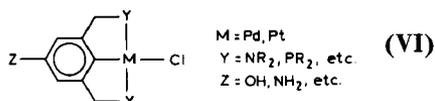
(tacycn = 1,4,7-triazacyclononane)

the palladium atom is effectively tetrahedral but the oxidation state is still more like Pd(II) than Pd(0). This unusual co-ordination geometry is reflected in the novel catalytic properties that are displayed, for example, the stereo- and regioselective addition of alcohols or carboxylic acids to electron deficient alkynes.

Ongoing studies of ruthenium and osmium catalysts for oxidation reactions were reported by Professor W. P. Griffith (Imperial College, London, U.K.). The ruthenium salt, $RuCl_3 \cdot xH_2O$, may be used in combination with a variety of readily available, environmentally friendly oxidants (hydrogen peroxide, sodium percarbonate, sodium peroxoborate) and phase transfer agents for the oxidation of alcohols and sulfides and other organic oxidations. The choice of co-oxidant can be extended to, for example, periodate (oxidative cleavage of alkenes and alkynes to carboxylic acids), persulfate and ozone (dehydrogenation of amines to nitriles).

Chelating Ligands

Pincer-type ligands which can bind 3 co-ordination sites have been studied by many groups due to interest in their influence on the physico-chemical and, in particular, catalytic properties of their complexes. Professor G. van Koten (University of Utrecht, The Netherlands) described work on linking these groups using the *para*-functionality Z (VI), so that arrays of

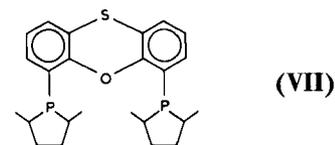


these metal complexes may be assembled. By choosing a core molecule with many potential

anchoring points, such as a dendrimer, many individual catalytic centres may be linked, allowing them to be separated from solution by ultrafiltration after completion of the reaction. The size and structure of the core can be controlled to give a flexible or a rigid molecular unit.

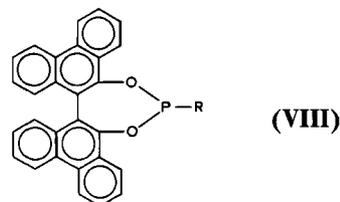
J. P. Rourke (University of Warwick, U.K.) described the chemistry of platinum complexes where diphenylpyridine behaves as a CNC-pincer ligand. While a CN-chelate forms readily, the second metallation reaction is less favoured. For the CN-chelate complexes, the interaction of the pendant phenyl group with the metal centre can play a significant role in substitution reactions of the complex.

Chelate ligands with large bite angles (VII)



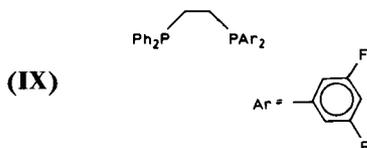
were described by P. C. J. Kamer (University of Amsterdam, The Netherlands). This allows steric contacts to maximise ligand influence in the transition state. Application of this principle produced effective catalysts for asymmetric allylic alkylation, Heck coupling reactions and Buchwald-Hartwig amination.

Work on P-donor ligands with platinum group metal complexes was described by P. G. Pringle (University of Bristol, U.K.). High enantioselectivities in asymmetric hydrogenation by rhodium are usually associated with bisphosphines where the ligand forms a rigid chelate, for example, the Duphos family of phospholanes. However, very large monodentate ligands may also yield high ees where extreme steric constraints prevent rotation about the metal-P



bond, for example (VIII). For many catalysts

requiring ligand dissociation to create a vacant site for substrate binding, the use of hemi-labile ligands (chelating ligands containing one strongly and one weakly binding group) can be advantageous. The strongly binding group is commonly a simple P-donor, such as -PPh_2 , while the weak donor may be O, N, S or P based. By synthesising a number of asymmetric 1,2-bis(diarylphosphino)ethanes, an effective ligand (IX) which can be used for methanol



carbonylation with rhodium or ruthenium, was identified.

Catalyst Screening

The identification of new catalysts using high throughput experimentation has attracted much interest recently. Professor R. H. Crabtree (Yale University, U.S.A.) described the use of a dye-based assay system for screening activity in hydrosilylation. By linking electron donor and acceptor groups with an olefin, dyes were obtained which were bleached when addition to the olefin occurred. The effectiveness of the procedure was confirmed using known active catalysts, such as Wilkinson's catalyst. Other rhodium and iridium complexes yielded active species but surprisingly a palladium complex gave the highest activity. The ability to prepare large numbers of well-defined catalysts is important for the effectiveness of high throughput work and this can be aided by linking suitable ligands to polymeric supports. Routes for obtaining supported phosphine ligands were described which could be reacted with metal precursor complexes to yield a library of rhodium and iridium catalysts.

Professor D. G. Blackmond (University of Hull, U.K.) showed how the calorimetric data from a single reactor could also be used for the evaluation of a number of catalysts. Heat output can be correlated with reaction rate, so, provided there is no interaction between catalyst

samples, the addition of a small amount of a new catalyst to a reaction will produce a step change in rate which is observed as an increase in heat output. Injections of further catalysts may be made and the results can be deconvoluted to obtain the separate contributions of each catalyst. The performance of a series of Pd/C hydrogenation catalysts was evaluated in this way. The detailed information on reaction kinetics provided by calorimetric measurement and kinetic modelling ensures that when a catalyst has been selected the reaction can be scaled up with a high degree of confidence.

Catalyst development through more traditional screening experiments was described by M. Studer (Novartis Services AG, Basel, Switzerland). In the development of a Rh/Pd on carbon catalyst for the stereoselective hydrogenation of a 2,4-disubstituted pyridine, both the relative loading of the two metals and the order of their precipitation onto the support were found to be important factors in maximising the amount of desired *cis* product. For the homogeneous enantioselective hydrogenation of an imine, an iridium catalyst containing a bisphosphine ligand derived from ferrocene was synthesised. This family of phosphines (Josiphos series) now extends to over 80 different derivatives.

Metal Particle Formation and Supramolecular Structures

Improvements in heterogeneous catalysis through control of metal particle formation featured in several talks. In concentrated surfactant solution micelles become ordered in close-packed arrays. Reduction of a metal salt in such a solution, where the metal ions are confined to the water phase, leads to the formation of a metal deposit with a specific pore structure equivalent to the micelle volume. G. S. Attard (University of Southampton, U.K.) reported on the use of this technique to obtain coarse platinum particles with a very high specific surface area of 40 to 60 $\text{m}^2 \text{g}^{-1}$. Particles of alloy can be formed from mixtures of metal salts. The pore size can be controlled by the addition of hydrocarbon to the solution, which has the effect of swelling the

micelles. Currently, these materials are being applied to gas sensing but further applications are likely, for example in fuel cell electrodes. B. Chaudret (CNRS, Toulouse, France) described the preparation of nanoparticles by reduction of metal complexes in the presence of a stabilising polymer such as polyvinylpyrrolidone. Monodisperse colloids with particles ranging from 1 to 10 nm diameter can be obtained. Again, by selecting appropriate mixtures of complexes for reduction, alloy particles are formed. Studying the magnetic properties of the particles allows deviations from bulk metal properties to be investigated.

The stabilisation of small metal particles by embedding in a mesoporous solid was described by Professor B. F. G. Johnson (University of Cambridge, U.K.). Mixed metal carbonyl clusters held in mesoporous silica can be decarbonylated more easily than in the "free" state giving mixed metal particles which resist sintering, even up to 400°C. This high temperature stability may give these materials potential as oxidation catalysts.

D. M. P. Mingos (Imperial College, London, U.K.) described studies of molecules designed to offer the possibility of multiple hydrogen bonding interactions, thus controlling their organisation in the solid state and in solution. In solution, a strong association was only seen when 3 H-bonds were formed between partner molecules. The photochemistry of a Ru/Os system linked in this way was described by M. D. Ward (University of Bristol, U.K.). Mingos also described how bidentate N and S donor ligands could bind to nickel ions to form a cage structure containing six metal atoms. Halide ions can be held within the structure by a combination of hydrogen bonding and Lewis acid-base interactions.

The topic of cage structures was taken further by Professor M. Fujita (Nagoya University, Japan). Using polypyridine-based ligands reacting with palladium complexes, cage structures were formed which can hold up to 4 molecules of adamantane within the cage. The structure becomes more rigid on cooling so large molecules, such as 2,4,6-tri-*t*-butylbenzene, enter-

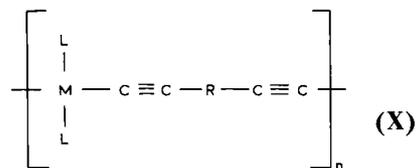
ing at high temperature can be trapped in the cage on cooling. The cage can also be used as a sterically constrained environment to promote certain reactions, such as Diels-Alder coupling. Using α,ω -bipyridyl ligands larger chains can be created which allows interlocking rings to be formed. With linear oligo-3,5-pyridine, nanotubes can be formed.

An alternative approach to form supramolecular structures using pyridine co-ordination was described by E. Alessio (Università di Trieste, Italy). By varying the substitution pattern on meso-pyridyl/phenyl porphyrins a range of symmetrical and unsymmetrical structures can be formed when metal complexes are bound to the peripheral N atoms. These complexes have potentially useful photochemical and redox properties.

Photochemical Properties

The study of the photochemical properties of mononuclear and dinuclear complexes, and the electronic structure underlying these effects was the subject of a number of talks.

P. R. Raithby (University of Cambridge, U.K.) described polymeric organometallic materials that may have potential for application in LED devices. These compounds (**X**) can be formed

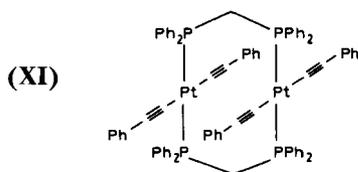


by a number of routes, of which dehydrohalogenation using *trans*-[MCl₂L₂], where M is Pt, Pd or Ni, and an acetylenic compound is probably the most widely applicable. The organic spacer R may be chosen from a wide variety of aromatic or heterocyclic groups allowing control of the photophysical properties.

The development of novel materials exhibiting non-linear optical properties was described by B. J. Coe (University of Manchester, U.K.). Suitable molecules contain an electron donor and acceptor functions separated by a π -system, good examples being *trans*-ruthenium complexes

$[\text{Ru}^{\text{II}}(\text{NH}_3)_4\text{L}_A\text{L}_D]^{n+}$ where L_A = acceptor ligand and L_D = donor ligand. H. Vos (Dublin City University, Ireland) reported the photochemistry of ruthenium bipyridyl complexes while J.-P. Sauvage (Université Louis Pasteur, Strasbourg, France) reported on terpyridyl complexes of ruthenium and iridium. Linking of donor and acceptor groups to the terpyridyl ligands creates complexes that can display long-lived charge separated states leading to interesting photochemical properties.

V. W. W. Yam (The University of Hong Kong, China) spoke about the luminescent properties of dinuclear platinum(II) acetylide complexes (XI). Luminescence is obtained when the



platinum-platinum distance in these compounds is in the range 3 to 3.5 Å. For compounds where this distance is influenced by the presence of other ions and molecules, the luminescence may be used for sensing and signalling devices.

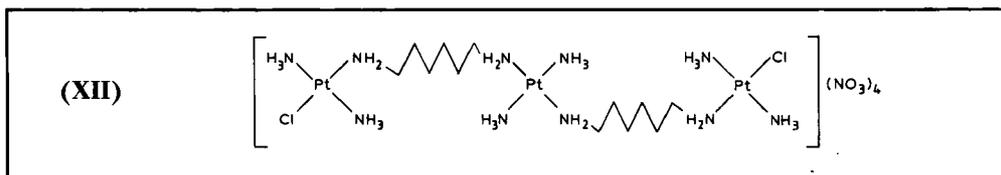
Theoretical studies of binuclear ruthenium complexes were reported by Professor A. B. P. Lever (York University, Toronto, Canada). Changes in the electronic structure through a series of redox reactions were measured by spectroelectrochemical methods and compared with data obtained by the ZINDO semi-empirical computational method. Professor J. M. Kelly (University of Dublin, Ireland) described work on the photochemical interaction of ruthenium polypyridyl complexes with DNA. On irradiation these complexes produce oxidative damage to DNA. Much stronger binding can be achieved with binuclear complexes, such as

$[(\text{phen})_2\text{Ru}(\text{Mebpy}-(\text{CH}_2)_n\text{-bpyMe})\text{Ru}(\text{phen})_2]^{4+}$ ($n = 5, 7$ or 10) than with the simple mononuclear compounds. Binding specificity can be achieved by linking the ruthenium species to an oligonucleotide sequence.

Electrochemistry of platinum group metal complexes was discussed by L. J. Yellowlees (University of Edinburgh, U.K.). The redox-active centre can be based either on the metal, the ligand or a molecular orbital spanning several nuclei. Studies using cyclic voltammetry can show whether the redox reaction is reversible or irreversible (that is, accompanied by a chemical reaction). By spectroscopic techniques such as EPR, localisation of the electron may be identified; for example, in $[\text{PtX}_2(\text{bipy})]$ a reversible one-electron reduction occurs at modest potential with the redox site being primarily based on the bipy ligand.

Biomedical Applications

Reports on biomedical applications of platinum group metals are a regular feature at these meetings, and on this occasion N. Farrell (Virginia Commonwealth University, Richmond, U.S.A.) described his work on platinum anti-cancer complexes, in particular on compounds which do not conform to the activity guidelines set out by Cleare and others in the 1970s. Recently, this work has focused on the trimeric compound code-named BBR3464 (XII). Individually each of the platinum atoms in this molecule has *trans* geometry, but overall the molecule has two labile sites for binding DNA. The compound shows much greater potency than cisplatin (~ 20 fold) in *in vivo* testing. Studies of DNA binding suggest that an inter-strand crosslink spanning over 3 base pairs is formed in contrast to the GG intrastrand crosslink formed by cisplatin. The positive charge on the central atom of the trimer seems



to be an important factor in the interaction with DNA thus contributing to the high potency. BBR3464 is now undergoing Phase I clinical trials in the U.K.

S. P. Fricker (AnorMED Inc., Langley, Canada) described the continuing development of ruthenium complexes as scavengers of nitric oxide *in vivo*. Nitric oxide has a number of functions in the body, but when there is an under or over production severe effects can result, such as septic shock with over production. Ruthenium(III) polyaminocarboxylate complexes react very rapidly with NO forming inert Ru(II) nitrosyls making them effective scavengers. The complexes are transported in the bloodstream but do not pass readily into cells, contributing to their low toxicity and limiting interference with essential NO functions. The effectiveness of the compound AMD-6221, [RuCl(H₃dtpa)] (dtpa = diethylenetriaminepentaacetate), in reversing hypotension has been demonstrated for endotoxaemia, but no clinical studies have been conducted to date.

Nitrogen Fixation

Nitrogen fixation has fascinated many researchers over many years. Recent work on the mechanism of the reaction was reported by Professor D. Sellmann (Universität Erlangen, Germany). Using deuterium labelling to study the transfer of hydrogen atoms in model ruthenium complexes, his work provides support for the 'diazene' mechanism of ammonia formation. X-ray crystallography has provided details of the enzyme active site, referred to as the "FeMoco" structure. A two-electron reduction is necessary before nitrogen binding and subsequent reactions.

The reverse reaction of ammonia oxidation to nitrogen is being studied by Professor R. A. van Santen (Eindhoven University of Technology, The Netherlands). The successive dissociation of hydrogen atoms from ammonia is endothermic, but the reaction can be made exothermic if oxygen is added so that hydrogen atoms are transferred to oxygen. Under these conditions, formation of N₂ is exothermic while formation of NO is endothermic, so selectivity

to N₂ is favoured by low temperature. Generally, the catalysts deactivate rapidly, which is thought to be due to coverage of the surface by NH.

Co-ordination Chemistry

M. W. George (University of Nottingham, U.K.) described the use of time-resolved IR spectroscopy to study the interaction of co-ordinatively unsaturated species with weak donor solvents such as alkanes, xenon and carbon dioxide. The activated complexes were generated by photolysis of carbonyl complexes. In scCO₂ the structures of the complexes may be deduced from their IR bands, allowing (η^1 -CO), (η^2 -CO) and (η^1 -O) bonding to be distinguished. The latter form was detected for the complex [Rh(acac)(CO)(CO₂)]. This bonding mode had previously only been observed at low temperature by matrix isolation. By following the reverse reaction with CO, the reactivity of this complex was found to be similar to that of [Rh(acac)(CO)Xe].

Professor B. R. James (University of British Columbia, Vancouver, Canada) reported on the reaction chemistry of co-ordinatively unsaturated ruthenium complexes containing PN bidentate ligands, such as *trans*-[RuCl₂(P-N)(PPh₃)] (P-N = *o*-(*N,N*-dimethylamino)-phenyldiphenylphosphine). These complexes react with a very wide range of small molecules to give octahedral complexes [RuCl₂(P-N)(PPh₃)L] of either *cis* (thiols, H₂S, nitrogen) or *trans* (water, methanol) stereochemistry.

Professor H. Werner (Universität Würzburg, Germany) discussed rhodium and iridium carbene complexes. Surprisingly, he found that while carbene complexes could not be prepared by direct reaction of [RhCl(P^{*i*}Pr₃)₂]₂ with diazocompounds, they could be obtained if [RhCl(Sb^{*i*}Pr₃)₂]₂ was used. Substitution of the stibine ligands by phosphines or arsines gave the desired compounds. Similar iridium compounds could be prepared from the mixed phosphine/stibine complex, [IrCl(C₂H₄)(Sb^{*i*}Pr₃)(P^{*i*}Pr₃)]. Further reactions of these complexes, in which the carbene ligand is retained, included the formation of dimeric complexes where the carbene acts as a bridging ligand.

R. F. Winter (Universität Stuttgart, Germany) described ruthenium complexes containing highly unsaturated systems. Intermediates generated by reaction of $[\text{RuCl}(\text{L}_2)_2]^+$ (L_2 = chelating diphosphine) with butadiyne may be trapped by reaction with amines, thiols, etc., to give a variety of products: secondary amines yield products $[\text{Cl}(\text{L}_2)_2\text{Ru}-\text{C}\equiv\text{C}-\text{C}(=\text{NR}_2)\text{CH}_3]^+$. Crystal structures suggest that the alternate resonance form $[\text{Cl}(\text{L}_2)_2\text{Ru}=\text{C}=\text{C}(\text{SR})\text{CH}_3]^+$ is favoured for the thiol adducts.

The isolation of the unusual complex $[\text{Pt}(\text{Me})(\text{OH})(\text{COD})]$ containing *cis* methyl and hydroxyl ligands was reported by A. Klein (Universität Stuttgart, Germany). The OH ligand will react with weakly acidic species HX yielding water and co-ordinated X (for example $\text{X} = \text{C}\equiv\text{CPh}$, CH_2COCH_3). Efforts to determine the *trans* influence of the hydroxyl ligand in these complexes by NMR spectroscopy suggested that it is similar to that of chloride.

Professor F. G. A. Stone (Baylor University, Waco, U.S.A.) reported on studies of carborane and metallocarborane as ligands. New complexes have been prepared where the BH vertices of the carborane form exo-polyhedral bonds with other metal complexes. Depending on the system, the carborane can act in mono-, bi- or tridentate bonding modes to the metal, with additional bonding from bridging hydrogen atoms. With metallocarborane ligands it is possible for both the metal and boron to chelate to a metal fragment.

One of the highlights of the meeting was the presentation by Professor A. von Zelewsky (University of Fribourg, Switzerland) on chirality in platinum group metal complexes. With the aid of his computer he brought the chemistry "to life", adding a musical accompaniment to the dancing atoms and structures flashed upon the screen. Behind the stylish presentation was a large volume of work on how the chirality of the ligands influences the structure of molecules, for example, the formation of dimeric species where only *R,R* or *S,S* forms are obtained and not *S,R* combinations.

Professor J. L. Spencer (Victoria University of Wellington, New Zealand) reported a detailed

NMR study of platinum bisphosphine alkane hydride complexes providing information on the intermediate structures in hydride migration/ β -elimination reactions. Extension of these studies to chelates containing bulky PN and NN ligands allowed identification of CH activation in solvents such as toluene and dichloromethane.

Further talks by Professor L. A. Oro (Universidad de Zaragoza-CSIC, Spain) dealt with the interaction of dinuclear iridium complexes with hydrogen and alkynes while Professor P. Braunstein (Université Louis Pasteur, Strasbourg, France) dealt with the application of Pd/Fe complexes for the formation of distannanes.

Concluding Remarks

Aside from the chemistry discussed and acquaintances renewed, lasting memories of the week will be a new acronym, COBALT (computers on benches all linked together – Tom Ziegler), a new standard for stability (inert to refluxing in DMSO – Martin Schröder) and a new standard in audio-visual presentation (Alex von Zelewsky). There is much to look forward to at the next meeting in this series to be held at the University of Southampton, U.K., in 2002.

Liquid Petroleum Gas Detection

In order to monitor and control environmental pollution, there is an increasing need to develop new sensors able to detect toxic and hazardous gases. Liquid petroleum gas (LPG), a mixture of hydrocarbons, is an extensively used fuel, but there has been little work on LPG sensors. Now, scientists from Italy and India have fabricated a gas sensor, based on bulk semi-conducting tin oxide and palladium, which is highly selective for LPG (A. R. Phani, S. Manorama and V. J. Rao, *Mater. Chem. Phys.*, 1999, **58**, (2), 101–108).

The tin oxide based sensor, containing 1.5 weight per cent of palladium and 35 weight per cent of aluminum silicate, was produced by sintering at 800°C for five hours. It showed great sensitivity (0.97) towards the selective detection of LPG in air at 350°C, even in the presence of carbon monoxide and methane. Tests carried out over a six months period at 200–400°C gave consistent results, ± 3 per cent, indicating its reliability with time.