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PLATINUM^{II/IV} AND RHODIUM^{III} CHEMISTRY VIEWED THROUGH NEW EYES: WHAT NEW SECRETS CAN ¹⁹⁵Pt and ¹⁰³Rh NMR SPECTROSCOPY REVEAL ABOUT SPECIATION AS RELEVANT TO REFINING SOLUTIONS?

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Abstract

Although some of the platinum(II/IV) and rhodium(III) chemistry is considered 'old' and well-known, the application of modern multinuclear NMR spectroscopic methods to this chemistry in solution reveals new details about their rich and relevant solution chemistry. In this paper we will briefly illustrate that the highly-sensitive ¹⁹⁵Pt NMR shielding is an excellent probe to explore aspects such as solvation, ion-pairing, and the hydrolysis chemistry of *inter alia* $[\text{PtCl}_{6-n}(\text{H}_2\text{O})_n]^{n-2}$ ($n=0-5$). Moreover the novel use of ³⁵Cl/³⁷Cl and ¹⁸O isotopes effects as unique NMR 'fingerprints' leading to a new and unambiguous method of chemical speciation of the numerous possible Pt^{II/IV} and Rh^{III} complexes present in halide-rich aqueous solutions. In the case of Rh(III) chemistry a new, direct speciation distribution diagram has been established for $[\text{RhCl}_n(\text{H}_2\text{O})_{6-n}]^{3-n}$ complexes ($n = 3-6$) in HCl solution at 292 K with these methods.

Introduction

The large-scale separation and refining of the platinum group metals (PGMs) is currently based largely on the favourable distribution properties between an aqueous and non-aqueous phase of their anionic chloro-complexes such as $[\text{PtCl}_6]^{2-}$, $[\text{PdCl}_4]^{2-}$, $[\text{RhCl}_6]^{3-}$ and $[\text{IrCl}_6]^{2/3-}$, while Ru and Os are generally separated by means of oxidative distillation^{1,2}. Currently these complex chloro-anions are separated and refined remarkably efficiently by means of a combination of classical methods (e.g. selective precipitation) and more modern solvent extraction, ion exchange, and even methods of molecular recognition. More recently, there appears to be a trend toward the development of simpler and more integrated separation and recovery schemes for the PGM chloro-anions based on modern solid materials that are PGM-selective, as exemplified by the potential chromatographic separation of the PGM anions developed by Schmuckler^{3,4} and others⁵. Generally, modern separation and recovery methods of the PGMs on a large scale (notably Pt(IV), Rh(III) and Ir(III/IV)), essentially depend on *the selective distribution* of the stable, kinetically inert, chloro-anions of these elements between mostly acidic, chloride-rich, aqueous phases and suitable non-aqueous (organic) receptor phases. The receptor phase may be either liquid or solid, and it is generally thought that the distribution mechanism involves ion-exchange or ion-association mechanisms.^{1-5,13}

The selectivity of the metal chloro-anion distribution between the two phases depends in turn on several factors, notably the *chemical speciation*⁶ of the respective PGM complexes in the acidic solutions. Moreover the thermodynamics of phase transfer and specifically the enthalpy and entropy of complex-ion transfer between the two phases determines the success of the separation, which in turn depends significantly on the nature of the primary (and possibly secondary) hydration shells of the complex PGM anions⁷⁻¹³.

This contribution will provide a brief overview of some aspects of our research over the past few years, in particular concerning *chemical speciation* of Pt(IV) and Rh(III) complexes in halide-rich acidic aqueous solutions, as relevant to real process solutions in the PGM refining and recovery industry. The efficiency and selectivity of the separation the PGM complexes from process solutions, is critically dependent on *the chemical species present in solution* of each precious metal at particular conditions. Thus for example, platinum is best separated if it is present exclusively in the form of $[\text{PtCl}_6]^{2-}$ using current refining methods. If, however, other species such as $[\text{PtCl}_5(\text{H}_2\text{O})]^-$ and even $[\text{PtCl}_4(\text{H}_2\text{O})_2]$ complexes are present in solution, the efficiency of separation is significantly compromised. In general, several methods of chemical speciation have been developed, which consist of *inter alia*⁶,

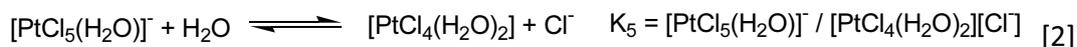
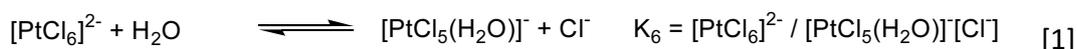
- (i) The fractionation (separation) of kinetically inert complexes by some chromatographic means
- (ii) A 'direct' spectroscopic method of identification of individual species in solution
- (iii) Or, as a last resort, the use of a combination of both fractionation and spectroscopic detection/identification of separated species using some form of 'hyphenated' methodology.

Nuclear magnetic resonance (NMR) spectroscopy is an ideal direct spectroscopic tool with which to explore the chemistry of Pt(II) and Pt(IV) complexes in view of the favourable properties of the relatively abundant ¹⁹⁵Pt isotope (approx. 33.8 per cent), which has a relatively high NMR receptivity (19.1), and an extraordinarily large chemical shift range ($\delta^{195}\text{Pt} > 12\,000\text{ ppm}$)¹¹. The ¹⁹⁵Pt NMR *chemical shift parameter*, $\delta^{195}\text{Pt/ppm}$, shows very high sensitivity to *inter alia* the structure and oxidation state of the platinum complex, as well as the nature of the ligands directly bound to the platinum atom/ion. For this reason, ¹⁹⁵Pt NMR has been widely applied as a spectroscopic tool in the study of the coordination chemistry of mainly square-planar Pt(II) complexes, most probably in view of the significant biological and catalytic properties that Pt(II) compounds display in many areas of research; this work has been widely reviewed¹⁴⁻¹⁷. Surprisingly relatively few ¹⁹⁵Pt NMR studies of octahedral Pt(IV) complexes, which are relevant to the refining industry, are reported in the literature. Moreover, the ¹⁰³Rh nucleus (100 per cent natural abundance, albeit at very low NMR receptivity of ca. 0.186), is also a useful spectroscopic tool to explore Rh(I/III) chemistry and speciation in relatively concentrated hydrochloric acid solutions¹⁸.

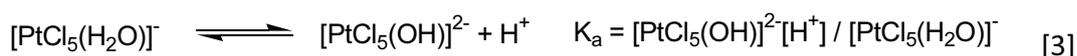
In the past decade we focussed on exploring the utility of high-resolution ^{195}Pt NMR spectroscopy for the direct speciation of platinum(IV) complexes in dilute hydrochloric acid solutions. In principle, in acidic solutions containing Pt(IV) and some chloride ions, up to nine platinum(IV) complexes can exist. We recently demonstrated the utility of ^{195}Pt NMR spectroscopy for the study of the speciation of $[\text{PtCl}_{6-n}(\text{H}_2\text{O})_n]^{n-2}$ ($n=0-5$) in solution, as well as illustrating the preferential extractability of $[\text{PtCl}_6]^{2-}$ over its corresponding aquated $[\text{PtCl}_5(\text{H}_2\text{O})]^-$ complex using diethylenetriamine-modified silica-based anion exchangers¹⁹. Moreover ^{195}Pt NMR allows for the direct speciation and full characterization of all 56 possible $[\text{PtCl}_{6-m-n}\text{Br}_m(\text{OH})_n]^{2-}$ ($m, n = 0-6$) complex anions in alkaline solution, some 30 of which have not been previously observed by any means²⁰.

^{195}Pt NMR spectroscopy as a means of speciation of platinum anions in chloride-rich aqueous solutions

In acidic aqueous solutions, the $[\text{PtCl}_6]^{2-}$ complex may undergo partial aquation forming the corresponding mono-*aqua* and di-*aqua* species as per Equations [1] and [2]; the quoted literature values of $\log K_6$ vary significantly from 1.5 - 2.2; only one reported value of $\log K_5 \sim 3.70$ is available in the literature:



Moreover at higher pH values aquated complexes such the $[\text{PtCl}_5(\text{H}_2\text{O})]^-$ may undergo hydrolysis to the hydroxido species; the $\text{p}K_a$ value for the hydrolysis of $[\text{PtCl}_5(\text{H}_2\text{O})]^-$ is ~ 3.5 , so that in reasonably acidic solutions hydrolysis can be assumed to be largely suppressed (Equation [3]):



The chemical speciation of Pt(IV) complexes in mildly acidic solutions is readily examinable by means of ^{195}Pt NMR spectroscopy¹⁹ as illustrated in Figure 1 for an 'aged' aqueous 0.48 M solution of made by dissolution of ' $\text{H}_2\text{PtCl}_6 \cdot 2\text{H}_2\text{O}$ '. The ^{195}Pt NMR spectrum of such solutions shows the presence of two species $[\text{PtCl}_6]^{2-}$ at 8 ppm and $[\text{PtCl}_5(\text{H}_2\text{O})]^-$ at 510 ppm, relative to the external reference solution ($500 \text{ mg cm}^{-3} \text{ H}_2\text{PtCl}_6 \cdot \text{H}_2\text{O}$ in 30 % v/v $\text{D}_2\text{O}/1 \text{ M HCl}$). The relative concentration (as measured by integrated ^{195}Pt peak NMR area) of $[\text{PtCl}_5(\text{H}_2\text{O})]^-$ was found to be between 18-20 per cent of the total concentration of platinum in solution (Figure 2). Although not discussed any further here, the relative *rates* of achieving chemical equilibrium in these solutions are significantly increased in the presence bright visible light¹⁹.

Very little quantitative species distribution data for 'H₂PtCl₆' in water can be found in the literature, so we examined the dependence of the relative amounts of [PtCl_{6-n}(H₂O)_n]ⁿ⁻² species for different total platinum concentrations [Pt]_t in equilibrated solutions. Figure 2 shows that the degree of aquation increases with decreasing total [PtCl₆]²⁻ concentrations at 30°C, presumably as a result of the mass action effect of water in Equations [1] and [2]. This is confirmed by the emergence of the additional ¹⁹⁵Pt NMR peak at 1006 ppm in the spectrum assigned to [PtCl₄(H₂O)₂], at a ~ 65 mM [Pt]_t solution as shown in Figure 2. In the most dilute solution ([Pt]_t ~ 6mM) reasonably measurable by means of ¹⁹⁵Pt NMR, the peak area due to [PtCl₄(H₂O)₂] contributes to almost 10 per cent of all the observable Pt species. Thus in more dilute solutions at least a third uncharged species [PtCl₄(H₂O)₂] is formed. The latter complex would not be expected to be separable by existing refining methods due to its uncharged nature, while the [PtCl₅(H₂O)]⁻ species is not as favourably extracted as the [PtCl₆]²⁻ species by ion exchange, so potentially resulting in less efficient overall platinum recovery. These findings highlight the importance of speciation.

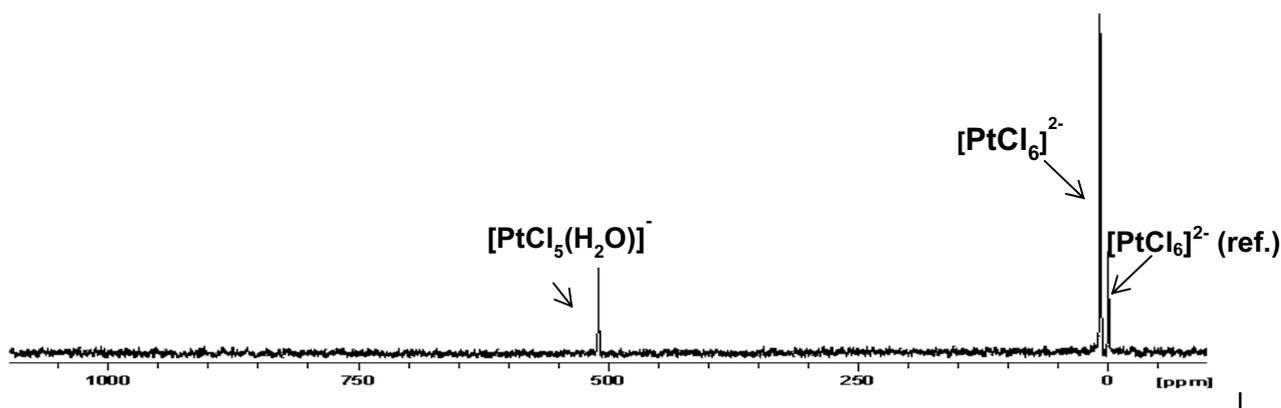


Figure 1- A 128MHz ¹⁹⁵Pt NMR spectrum at 30 °C of a 0.48M aqueous solution prepared from solid "H₂PtCl₆·2H₂O". For convenience we use as reference compound a solution of [PtCl₆]²⁻ in 1.0 M HCl in a coaxial 1mm tube¹⁹.

Although in the context of large-scale refining of the PGMs, the high HCl concentrations (2-6 M) that are routinely used would be expected to suppress the formation of aquated Pt complexes of type [PtCl_{6-n}(H₂O)_n]²⁻ⁿ (n= 0-5), we have examined a limited number of authentic process solutions, which show detectable quantities of species *other* than that of the desired complex [PtCl₆]²⁻ are observable by means of high-resolution ¹⁹⁵Pt NMR. Unfortunately, confidentiality agreements prevent the disclosure of spectra of authentic process solutions. For this reason we carried out a systematic full speciation study of platinum(IV) complexes in acidic media.

Our hypothesis is that minor species detected in solution may be present partly because in solutions that contain relatively large concentrations of Pt(IV) together with other (PGM) halide-coordinating metals, a nominal HCl concentration of 6M does not necessarily result in an excess of 6M *chloride ions*, since substantial proportions of Cl⁻ ions will actually be bound to Pt(IV) and other metal ions, so that the thermodynamic activity of the Cl⁻ ion is lower than anticipated, and the total HCl concentration is not an accurate reflection of the activity of the Cl⁻ ion. This phenomenon is well illustrated in the case of concentrated Rh(III) solutions in 6 M HCl, in which the speciation observed by means of ¹⁰³Rh NMR depends more directly on the effective Rh(III):Cl⁻ ion ratio, rather than nominal HCl concentration. As will be illustrated below, the use of ¹⁰³Rh NMR leads to the first directly determined speciation distribution diagram for [RhCl_n(H₂O)_{6-n}]³⁻ (n = 3-6) as a function of uncoordinated Cl⁻ ion concentration, resulting in a speciation distribution somewhat different in quantitative aspects to published data.

In this paper we present the basic principles of the NMR methodology developed by us using synthetic Pt and Rh solutions, which are not entirely identical to a process feed or raffinate solutions.

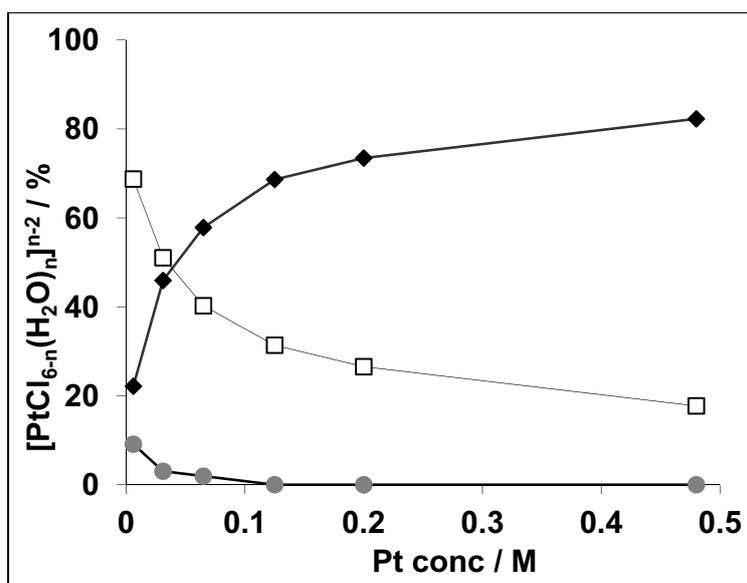


Figure 2-Relative amounts of [PtCl₆]²⁻ in a 0.48 M aqueous solution prepared from solid “H₂PtCl₆·2H₂O” (at fixed Cl:Pt mole ratio of 6) as determined by ¹⁹⁵Pt NMR (as peak areas %) of (♦), [PtCl₅(H₂O)]⁻ (□) and [PtCl₄(H₂O)₂] (●) species in aqueous solutions as a function of differing total Pt(IV) concentrations¹⁹.

As part of our research on the oxidation of precious metal complexes in aqueous solutions with industrially-utilized oxidants such as sodium chlorate (NaClO₃) and bromate (NaBrO₃), we have found ¹⁹⁵Pt NMR an excellent tool with which to study the oxidation of [PtCl₄]²⁻.

Surprisingly, very few reported studies using sodium chlorate (NaClO_3) and bromate (NaBrO_3) exist in the open literature concerning both the products and the possible mechanism of oxidation of Pt(II) compounds to Pt(IV) species. We recently reported a full study of the oxidation of $[\text{PtCl}_4]^{2-}$ in acidic aqueous media by NaClO_3 or NaBrO_3 (or mixtures of both these oxidants), which proceeds readily at 50°C to result in complete oxidation of Pt(II), but yields a surprising number of Pt(IV) product species in acidic solution (Figure 3)¹⁸. A noteworthy result of this work is that the relative rate of oxidation of Pt(II) using NaBrO_3 is found to be significantly higher than that with NaClO_3 . A typical ^{195}Pt NMR spectrum of the products resulting from the oxidation of $[\text{PtCl}_4]^{2-}$ with a 5 mole equivalent excess of NaClO_3 in 1 M perchloric acid is shown in Figure 3. In the case of using a mixture of NaClO_3 or NaBrO_3 as oxidants, an even larger number of mixed-halide species are obtained in solution¹⁸.

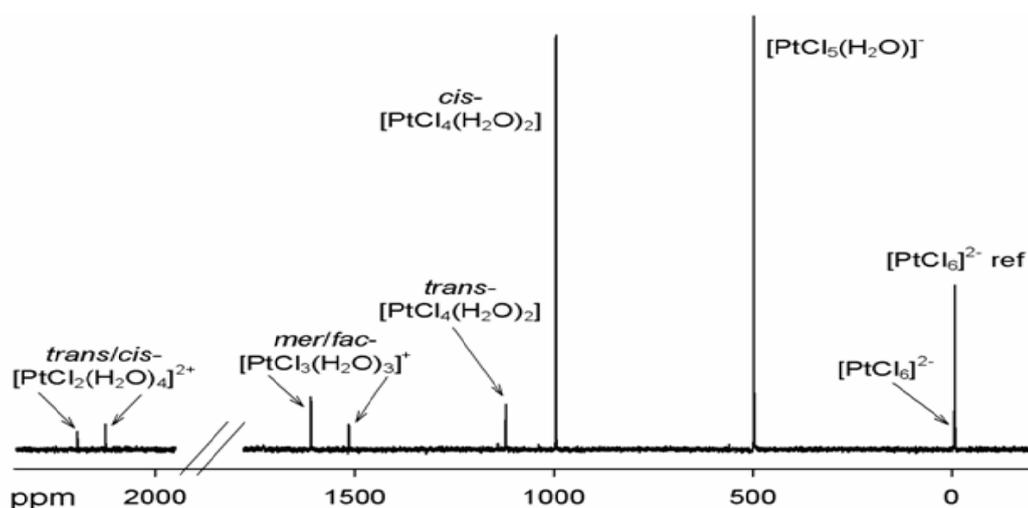


Figure 3- ^{195}Pt NMR spectrum of 0.2 M K_2PtCl_4 in 1 M HClO_4 oxidized at 50°C for 10 min with 5 mole equivalents of NaClO_3 showing the formation of several species in solution at steady state²¹.

Although the peaks in the ^{195}Pt NMR spectrum (as shown in Figure 3) can be assigned by chemical-shift-trend analysis methodology¹⁹, this procedure is tedious and time-consuming. In this context we thus developed a rapid direct method of spectroscopic speciation of Pt(IV) complexes by exploiting the natural isotopic distribution of $^{35}\text{Cl}/^{37}\text{Cl}$ isotope effects on the ^{195}Pt NMR peak of an individual species, which has at least one chlorido-ligand bound to a Pt(IV) ion. This approach proved to be remarkably successful²²⁻²⁴.

$^{35/37}\text{Cl}$ and $^{16/18}\text{O}$ isotope effects as unique ^{195}Pt NMR spectroscopic fingerprints of the series of $[\text{PtCl}_{6-n}(\text{H}_2\text{O})_n]^{2-n}$ ($n = 0-5$): a new method of speciation of Pt(IV) complexes in solution

The very high sensitivity of the ^{195}Pt NMR shielding to subtle changes in the electronic structure in each individual complex is beautifully illustrated by the $^{35/37}\text{Cl}$ isotope induced fine-structure of the ^{195}Pt NMR peaks of Pt(IV) complexes with at least one halide ion bound, recorded using high-magnetic field (14.1 T) NMR spectrometers and under carefully controlled conditions in solution²². Significant isotope effects are evident on expansion of all individual ^{195}Pt NMR peaks shown in Figure 3. Thus for $[\text{PtCl}_6]^{2-}$ species, one observes seven isotopologues ranging from $[\text{Pt}^{35}\text{Cl}_6]^{2-}$ to $[\text{Pt}^{37}\text{Cl}_6]^{2-}$ depending on the statistical distribution of the $^{35/37}\text{Cl}$ isotopes bound to the platinum ion; this is reflected in a seven-line pattern in the ^{195}Pt NMR peak, in which each isotopologue has a slightly different $d(^{195}\text{Pt})$ chemical shift.

As can be seen in Figure 4, the ^{195}Pt NMR peaks for selected members of the nine possible complexes of the $[\text{PtCl}_{6-n}(\text{H}_2\text{O})_n]^{(n-2)}$ ($n=1-5$) series are well resolved into a unique line-shape resulting from the statistically possible isotopologues and isotopomers possible for a particular platinum(IV) complex. These isotope effects resolved in the ^{195}Pt resonance constitute a unique and unambiguous 'spectroscopic fingerprint' for a specific Pt complex containing at least one bound chlorido ligand in this series. For example, for the $[\text{PtCl}_5(\text{H}_2\text{O})]^{1-}$ complex six isotopologue peaks are expected, but in view of the possibility of isotopomers (*isotopic isomers*) resulting from whether a coordinated water molecule is bound *trans* to a ^{35}Cl or a ^{37}Cl ligand in the octahedral platinum complex induces additional fine-structure in the ^{195}Pt peak shape due to the existence of such isotopomers in a 1:4 statistical ratio. Particularly interesting is the difference observed in the peak shape of the ^{195}Pt NMR resonances of the stereoisomer pairs *cis/trans*- $[\text{PtCl}_4(\text{H}_2\text{O})_2]$, *fac/mer*- $[\text{PtCl}_3(\text{H}_2\text{O})_3]^+$, and *cis/trans*- $[\text{PtCl}_2(\text{H}_2\text{O})_4]^{2+}$, which show non-identical line shapes, so enabling the ready distinguishing of such isomers from their ^{195}Pt NMR peaks in solution *without* regard to accurate chemical shifts, something not previously possible by any other spectroscopic means to our knowledge.

Using this reasoning, it is possible account for the unique fine-structure of all ^{195}Pt resonances of these complexes in this a series, illustrated in Figure 4. This remarkable spectroscopic fingerprint for each of the platinum species in solution constitutes a new method for their rapid and unambiguous identification in solution. Moreover, this method can be extended to the corresponding hydroxido-complexes in solution²⁴, such as the series of $[\text{Pt}^{35/37}\text{Cl}_{6-n}(\text{OH})_n]^{2-}$ ($n=0-5$) anions, which is readily obtained in strongly alkaline solutions containing $[\text{PtCl}_6]^{2-}$.

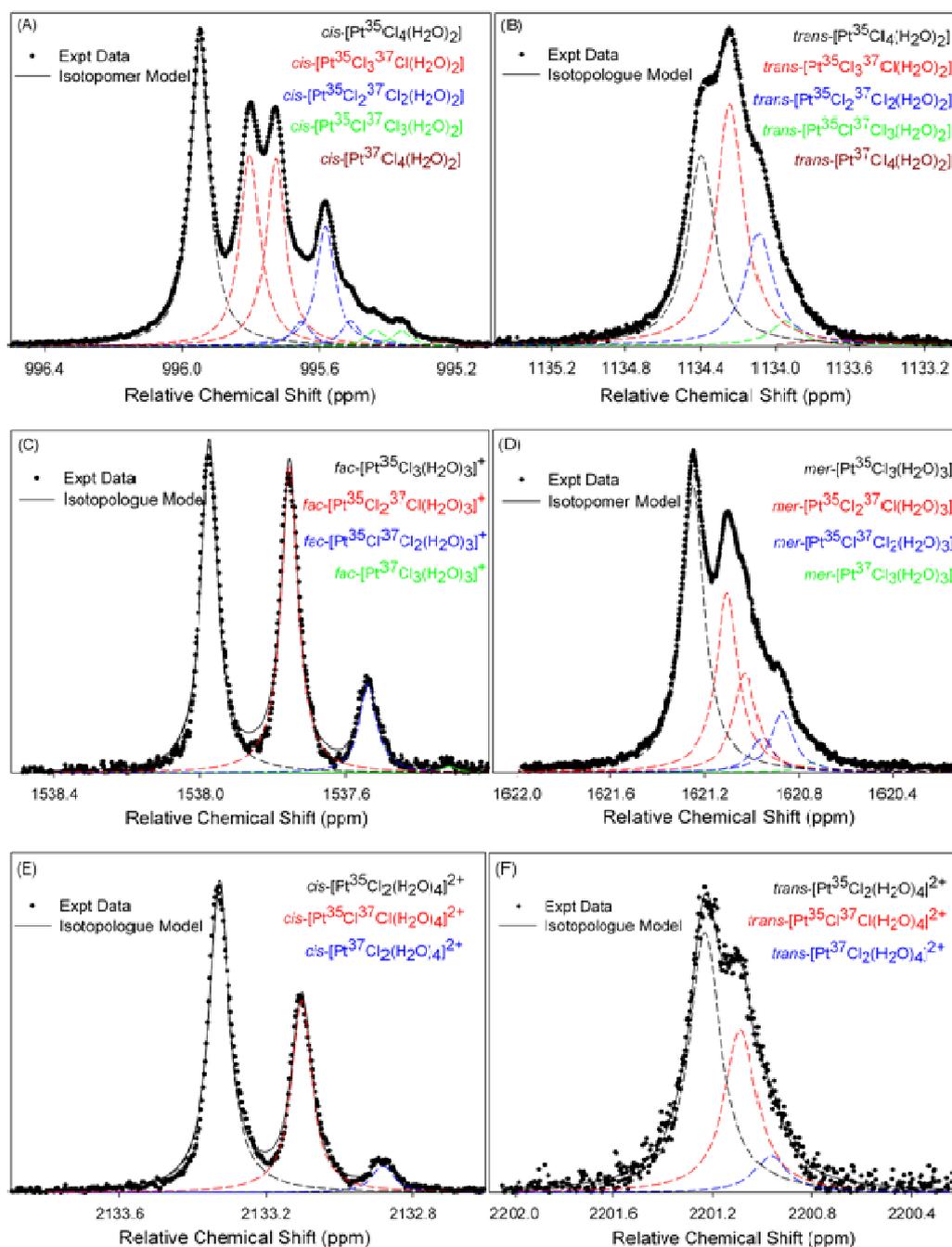


Figure 4-Expansions of ^{195}Pt NMR spectra of *cis/trans*- $[\text{PtCl}_4(\text{H}_2\text{O})_2]$ (A and B) *fac/mer*- $[\text{PtCl}_3(\text{H}_2\text{O})_3]$ (C and D) and *cis/trans*- $[\text{PtCl}_2(\text{H}_2\text{O})_4]$ (E and F) at 293 ± 0.1 K. The excellent least-square fit (solid lines) between the experimental spectra (\bullet) in terms of statistically possible isotopologues and, where appropriate, isotopomers (colour simulations) for these complexes is clear²³.

Although not shown here, the 'spectroscopic fingerprints' based on the $^{35/37}\text{Cl}$ isotope effects can be supplemented and confirmed by addition of partially ^{18}O enriched water, H_2^{18}O , which results in additional unique ^{18}O -induced isotope effects for each platinum species to which at least one water molecule is bound, or in alkaline solutions one OH^- ion bound to a platinum ion²³.

In summary, the interesting isotope 'fingerprint' effects demonstrated above for a ^{195}Pt NMR peak of the complexes studied to date are a general feature in such NMR spectra, and thus greatly assist in the *direct spectroscopic speciation* and of Pt(IV) complexes in acidic halide ion-rich solutions, as well as in strongly alkaline solutions, which contain the corresponding stable hydroxido-chlorido platinum(IV) complexes.

Speciation of $[\text{RhCl}_n(\text{H}_2\text{O})_{6-n}]^{3-}$ ($n = 3-6$) complexes using ^{103}Rh NMR: a direct speciation distribution diagram

Recently, we extended a NMR isotope-based spectroscopic method of speciation as described for platinum complexes above, to the corresponding Rh(III) complexes in acidic chloride-rich solutions for the first time. Although the ^{103}Rh nucleus is 100 per cent naturally abundant, the overall NMR receptivity of this nucleus is much lower than ^{195}Pt , which poses some challenges in the practical measurement of ^{103}Rh NMR spectra directly¹⁸. Nevertheless we have recently shown that direct 19.11 MHz ^{103}Rh NMR in concentrated Rh(III) solutions (0.4-0.7M), allows for the unambiguous identification of the series of $[\text{RhCl}_n(\text{H}_2\text{O})_{6-n}]^{3-n}$ complexes ($n = 3-6$) in HCl solution at 292 K, and under carefully optimized temperature and magnetic field homogeneity²⁵. The ^{103}Rh NMR signals display very similar $^{35/37}\text{Cl}$ isotopologue/isotopomer resolved NMR peaks as observed for the ^{195}Pt NMR spectra, provided $^{35/37}\text{Cl}$ ions are bound the rhodium(III) and the spectra. Thus this approach not only allows for the direct spectroscopic speciation of Rh(III) complexes in concentrated HCl solutions (1-6 M HCl), but enables a direct speciation distribution diagram for Rh(III) species as a function of 'unbound' Cl^- ion concentration to be constructed for the first time, which we believe may be currently the most accurate available²⁶. The published species distribution diagrams for Rh(III) have been generally constructed using data from indirect (kinetic and spectrophotometric) measurements in *dilute* Rh(III) solutions at high nominal HCl concentrations, for which the Rh(III): Cl^- mole-ratio is rather higher than those that may be expected in actual process solutions.

In summary, it is clear that ^{195}Pt and ^{103}Rh NMR is a powerful spectroscopic tool for studying the deceptively simple chemistry of these precious metals in solutions as relevant to the refining industry. The knowledge of such speciation as a function of chloride ion concentration can potentially result in optimization of Pt, and certainly Rh, recovery by careful speciation control. Despite this, NMR spectroscopy has some limitations, which include principally the relatively high cost of high-field NMR spectrometers and the fact that these are not widely available in the industrial setting.

One other limitation of NMR spectroscopy is that the relative sensitivity is comparably low, so that the lower limits of detection of species concentrations is limited the millimolar concentration levels. Finally, to this end we have developed separation techniques complementary to our NMR studies that are capable to carry out speciation in the sub-millimolar to micromolar concentration levels. One such study has revealed that our ^{195}Pt NMR spectroscopy studies have helped validate a reversed-phase ion-pairing HPLC (RP-IP-HPLC) speciation study of mixtures of Pt(IV)-chlorido and bromide species at concentrations levels 100-fold *or more lower* than accessible by means of ^{195}Pt NMR spectroscopy^{27,28}. The complementarity of these approaches is pleasing. We are actively pursuing such studies to understand the solution chemistry as well as developing methods of speciation for several members of the PGMs using a variety of new and complementary spectroscopic and separation techniques.

Acknowledgements

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The Author



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Born in Windhoek Namibia, Klaus R Koch attended St Paul's College matriculating in 1972, before obtaining a BSc (*with distinction in Chemistry*) in 1975, a BSc (Hons) *first class* in 1976 and a PhD from the University of Cape Town in 1979. His PhD thesis entitled 'Heavy Metal Interactions with Nuclei Acid Derivatives: A Nuclear Magnetic Resonance Study' concerned model studies of the then newly discovered anti-cancer drug '*cisplatin*' based on the remarkably simple platinum complex *cis*- $[\text{PtCl}_2(\text{NH}_3)_2]$ a drug which is still in use today. In 1980, he was appointed lecturer in a newly established Department of Analytical Science at UCT on the initiative of the renowned inorganic and analytical chemist, Professor H M N H Irving, father of the 'Irving and Williams' stability trend well-known to inorganic chemists of the day. After a sabbatical at Merton College in Oxford (UK) in 1982/3, he returned to Cape Town, and helped build the Department of Analytical Science, being promoted from senior lecturer (1983) to acting-head of this department in 1988, and associate professor (1989).

Professor Koch spent several periods of study abroad *inter alia*, visiting Heinrich Herz Fellow at the University of Paderborn in Germany (1986), visiting Fellow at Robinson College and the Inorganic Chemistry Laboratory, Cambridge (UK) (1993), a DAAD Senior Fellowship at the Inorganic Chemistry Institute of the Technical University of München and Leipzig University in Germany (1997). Koch was visiting DAAD professor at the Institute of Inorganic Chemistry and Mineralogy at Leipzig University in 2007/8 for four months.

In 2000 he was appointed Professor of Analytical Chemistry at Stellenbosch University where established the Platinum Metals Chemistry Research Group. In January 2009 he was appointed executive Head of the Department of Chemistry and Polymer Science. He is member of the Royal Society of Chemistry, the American Chemical Society and the SA Chemical Institute and was elected Fellow of the Royal Society of South Africa in 2002. Professor Koch was chairman of the organising committee and responsible for bringing the 37th International Conference on Coordination Chemistry (ICCC) to Cape Town after a 20 year period of lobbying; it was the first-time that an ICCC, one of the longest running inorganic chemistry conferences, was held on African soil. The event attracted 620 delegates from 57 countries

Koch's research and teaching interests concern two inter-related aspects of the analytical and coordination chemistry of the platinum group metals (PGMs), important to the South African economy. At the core of his interest is the synthesis of molecules for selective complex formation of platinum group metal and materials for separation and recovery of *inter alia* platinum, palladium and rhodium. The use of modern multi-nuclear Magnetic Resonance Spectroscopy (NMR) to fundamental chemical questions in this context is a lifelong interest, as well as the use of modern separation techniques coupled to atomic spectroscopy for separation and speciation of PGMs. He has published 131 peer reviewed papers (including one patent) to date, and has received numerous invitations to contribute to specialist national and international conferences and in the period 1981 to date. He has supervised numerous BSc(Hons) projects students and 31 MSc (seven with distinction/*cum laude*) and 14 PhD degrees have been awarded under his supervision to date.

