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Laboratories and Demonstrations

Geometric Isomers of Platinum Coordination Compounds: An NMR Experiment for the Undergraduate Inorganic Chemistry Laboratory

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This experiment demonstrates, in a simple fashion, the use of heteronuclear NMR in inorganic chemistry.

This experiment illustrates the value of using NMR spectroscopy to study geometric isomers, and the synthetic utility of the trans effect in inorganic reaction mechanisms. The syntheses of *cis*- and *trans*-diamminedichloroplatinum(II) are carried out on a small scale, using both ^{14}N and ^{15}N ammine ligands. Students use ^{195}Pt and ^{15}N NMR spectroscopies to study the coordination complexes prepared. The ^{195}Pt chemical shift is indicative of the metal's coordination environment. Furthermore, the ^{195}Pt–^{15}N coupling constant is sensitive to the nature and geometry of the ligands bound to the metal, and this is also explored.

Introduction

The experiment described here introduces heteronuclear NMR techniques into the undergraduate laboratory by having students examine complexes using ^{195}Pt and ^{15}N NMR

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spectroscopies. Students have performed this experiment in our Advanced Inorganic Laboratory course, which is an elective taken in the junior or senior year. At this level, our students are familiar with the basic operation of our NMR spectrometer and have acquired routine ^{1}H and ^{13}C spectra in the organic chemistry laboratory. This particular course has two hours of lecture and four hours of laboratory per week. Typically, the class size ranges from 12 to 20 students.

^{195}Pt is an excellent spin-1/2 nucleus to study because its generally short relaxation times allow for rapid accumulation of spectra with little waiting time between pulses. First-time users of the technique should be aware, however, that the large possible range of chemical shifts means that some time is necessary to initially find the signal. Once the correct parameters are in hand, ^{195}Pt spectra are quick to obtain. ^{195}Pt chemical shifts and ^{195}Pt–^{15}N coupling constants are sensitive to the geometry of the complex, and are useful tools in evaluating the nature of the coordinated ligands. The preparation of platinum coordination complexes illustrates the synthetic utility of the trans effect in the synthesis of inorganic complexes (Figure 1) [1]. Simple inert complexes can be produced in a single laboratory period (3–4 hours). The ammine platinum(II) examples selected for study in this case are molecules with important chemotherapeutic uses that stimulate much discussion of bioinorganic chemistry in class.

Although ^{15}N has a very low natural abundance (0.37%) and low NMR sensitivity, it is a superb companion to ^{195}Pt in this undergraduate experiment. In contrast to ^{195}Pt NMR acquisition parameters, those applied to ^{15}N NMR must take into account longer relaxation times and a delay between pulses. Employing ^{15}N NMR spectroscopy in this experiment serves as a means to introduce students to inorganic NMR methods that employ polarization transfer since, in this case, a DEPT pulse sequence is employed to obtain the spectra. The use of ^{15}N-labeled starting materials is a good way to have students consider the importance of isotopic abundance to NMR spectroscopy. Furthermore, the difference in the ^{195}Pt NMR between the ^{14}N and ^{15}N products is dramatic; it also serves to show the effects of quadrupolar broadening on the appearance of a spectrum.

The experiment is designed as a cooperative project. Students work in teams of four. Each member of the group is responsible for the synthesis of one of the four complexes: *cis*-$(NH_3)_2PtCl_2$ or *trans*-$(NH_3)_2PtCl_2$, using labeled or unlabeled NH_3. The

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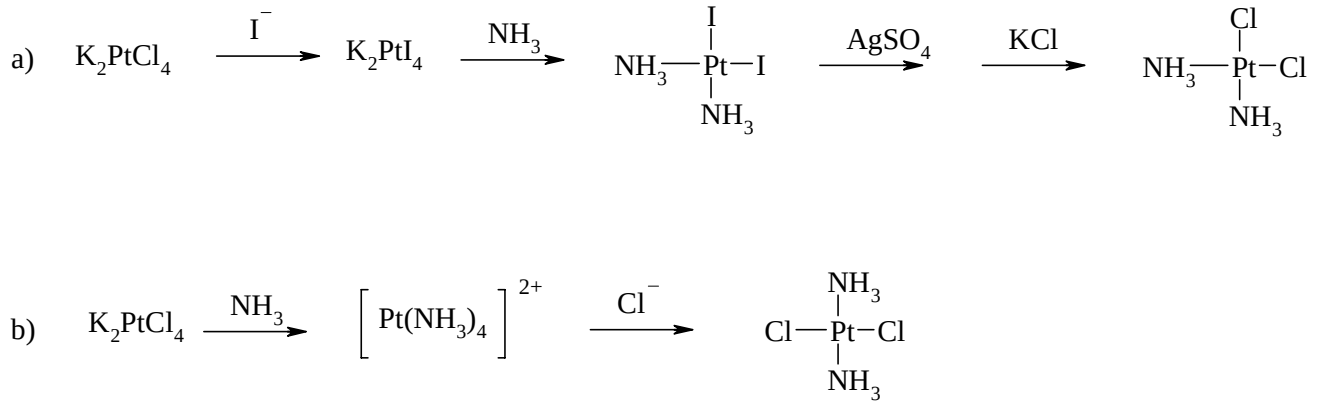

FIGURE 1. SYNTHESIS OF CISPLATIN AND TRANSPLATIN.

students then obtain a ^{195}Pt NMR spectrum of their samples. Those who prepare labeled samples also acquire ^{15}N spectra, but those with unlabeled NH_3 ligands perform a spectral simulation exercise instead. The team then compares and evaluates all of the spectra. The formal laboratory report includes information that pertains to both group and individual results. The spectra in both this article and its supplementary material were generated by students.

Experimental

General Information

^{15}N-labeled materials are available from Cambridge Isotope Laboratories. Platinum complexes, purchased from Strem Chemical, are recovered at the end of the experiment and saved for recycling [2]. On the scale used here, the cost for the experiment is quite reasonable. The ^{15}N-labeled materials are cheaper than platinum reagents. Each team of four students requires 0.5 g K_2PtCl_4 and 0.5 g of $^{15}NH_4NO_3$ or $^{15}NH_4OAc$.

Safety Precautions

Cisplatin is a potent antitumor agent that is mutagenic and carcinogenic in animals [3]. K_2PtCl_4 is allergenic. Care should be taken to avoid skin contact, inhalation, and ingestion of platinum compounds. Gloves should be worn when working with these substances.

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Synthesis of Cisplatin

A microscale literature procedure [4] was followed, and it led to good yields of *cis*-$(NH_3)_2PtCl_2$ from 125 mg of K_2PtCl_4. The labeled material, *cis*-$(^{15}NH_3)_2PtCl_2$, was produced by substituting a 2.0 M solution of $^{15}NH_4NO_3$ (pH adjusted to 5 with 2 M NaOH) for the required NH_3 solution.

Synthesis of Transplatin

A solution of 50 mg K_2PtCl_4 in 2 mL H_2O in a conical vial equipped with a spin vane was heated to just below boiling on a hot plate. Then, 100 mg ammonium acetate in 1 mL H_2O was added to the hot solution. The reaction was stirred while the volume was reduced to approximately 0.5 mL. The mixture was chilled on ice to produce off-white needles. Approximately 1.5–2 mL of 6M HCl was then added, and the solution was heated again. The volume was carefully reduced to 0.5–0.75 mL and then the mixture, which was already yellow and cloudy, was cooled on ice. The yellow solid was collected by filtration, washed with three 0.1-mL portions of ice-cold water, followed by three 0.1-mL portions of cold ethanol, and allowed to air dry. More transplatin can be obtained from the filtrate by repeating the treatment with HCl and evaporating the solution again. The labeled material was prepared using $^{15}NH_4OAc$.

NMR Spectroscopy

NMR spectra were recorded with a Varian Gemini 300 spectrometer using a 5-mm broadband probe. The sample of *cis*-$(NH_3)_2PtCl_2$ (5–8 mg) was dissolved in dimethylformamide (DMF). Deuterated DMF (10%) may be added as an internal lock, but it is actually unnecessary for this experiment. NMR samples of *trans*-$(NH_3)_2PtCl_2$ were prepared by saturating DMF with the complex.

^{195}Pt spectra (64.5 MHz) were collected using a 90° pulse. The data for unlabeled material were collected with a 0.05-s acquisition time and a spectral width of 25 kHz. Spectra were processed with line broadening (200 Hz) and zero filling (16 kB). Data for ^{15}N labeled complexes were collected with a 0.15-s acquisition time and ^{1}H decoupling. The spectra were processed with line broadening (50 Hz) and zero filling (16 kB). ^{195}Pt chemical shifts were externally referenced to a sample of 0.10 M K_2PtCl_4 in D_2O (25 °C) at –1624 ppm.

^{15}N spectra (30.40 MHz) were collected using a DEPT pulse sequence with a 1.75-s acquisition time and a 9-kHz spectral width. The delay time was $1/(2J)$ as calculated

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from $^{1}J(^{15}N–^{1}H)$ = 75 Hz. ^{15}N chemical shifts were externally referenced to formamide at –268 ppm.

Spectral Simulation

One-dimensional ^{195}Pt and ^{15}N NMR spectra were calculated using the program gNMR for Windows [5]. Chemical shift and coupling-constant data were obtained from the literature [6].

Results and Discussion

The complexes used in this laboratory experiment can be prepared in a three to four hour lab period. Spectra are acquired over two additional days, with the first devoted to ^{195}Pt NMR and the second to ^{15}N NMR.

The platinum signals for the cis and trans isomers are generally well-separated in the spectrum, and the peak assignments can be readily made. For complexes of the type PtL_2X_2, where L is a soft ligand and X is a hard one, the chemical shifts of cis and trans analogues differ by as much as 500 ppm [7]. When the ligands L and X are more similar, as in this case, the difference is much less.

Transplatin is roughly eight times less soluble in water than is cisplatin, producing solutions too dilute to obtain spectra in a reasonable amount of time. Therefore, spectra were acquired in dimethylformamide, which dissolves each complex in suitable concentrations. Figure 2 shows the ^{195}Pt NMR spectra of ^{14}N and ^{15}N *cis*-$(NH_3)_2PtCl_2$. The difference between the two clearly demonstrates the effect of the significant electric quadrupolar moment of ^{14}N (I = 1) in several areas. First, the line width of the Pt signal is greatly influenced by the ligands; $\Delta\nu_{1/2}$ for *cis*-$(NH_3)_2PtCl_2$ is 715 Hz. Values this great can occur for Pt complexes of ^{14}N because coordination of the lone pair slows ^{14}N relaxation [7]. Slow ^{14}N relaxation adversely affects T_2, which is not short enough to completely decouple ^{14}N and ^{195}Pt. Thus, the Pt peak is broadened and the pentet expected from ^{14}N splitting is masked. On the other, the ^{15}N-labeled samples produce spectra with distinct spin–spin coupling. Chemical shifts and coupling constants for the complexes studied are summarized in Table 1. ^{195}Pt chemical shifts are particularly sensitive to solvent, temperature, and concentration, thus, students learn the importance of reporting experimental conditions when comparing the

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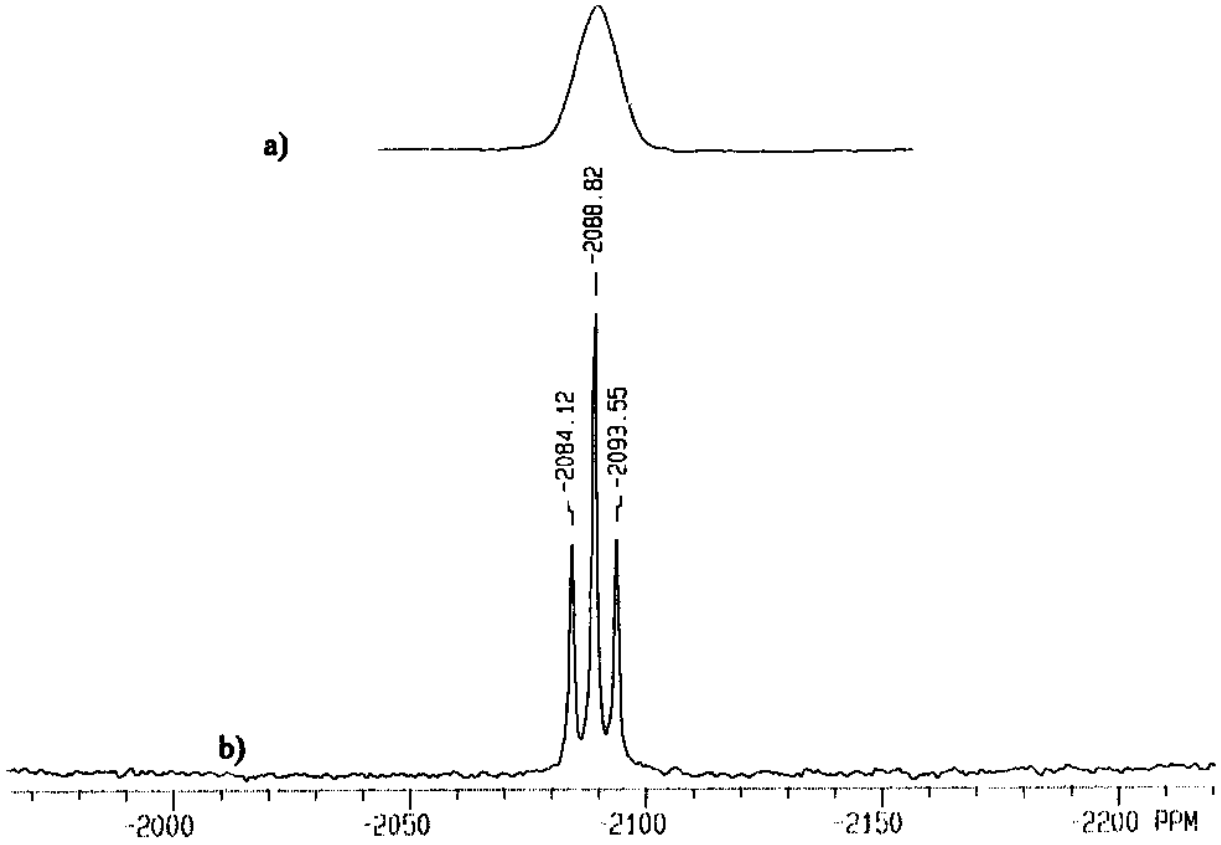

FIGURE 2. ^{195}Pt NMR OF (a) ^{14}N- AND (b) ^{15}N-LABELED *cis*-$(NH_3)_2PtCl_2$ COMPLEXES.

TABLE 1. Chemical shift (ppm) and coupling-constant (Hz) values.

Complex	Solvent	^{195}Pt	^{15}N	$J(^{15}N–^{195}Pt)$
cis-$(NH_3)_2PtCl_2$	DMF	–2089	–126.2	303
	D_2O	–2149	---	330
trans-$(NH_3)_2PtCl_2$	DMF	–2101	–126.1	280
	D_2O	–2145	---	---

literature data [8], obtained in H_2O, with their own data obtained in DMF. Typically, for the same solvent and temperature, errors are at most only a few ppm.

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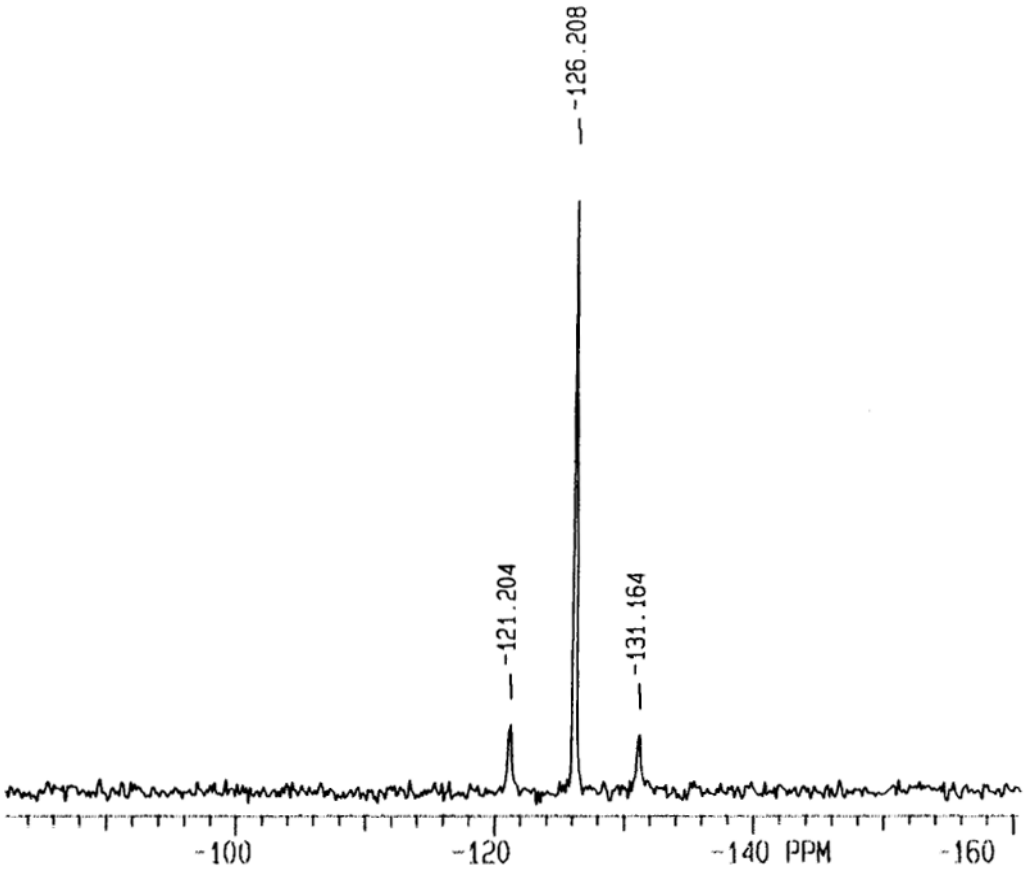

FIGURE 3. ^{15}N NMR OF *cis*-$(^{15}NH_3)_2PtCl_2$ IN DMF.

More accurate information about coupling constants can be obtained from ^{15}N NMR spectra (Figure 3), since the temperature dependence of the ^{15}N chemical shifts is less than that of the ^{195}Pt shifts. Using a DEPT pulse sequence (Figure 4) to obtain data for ^{15}N spectra results in sensitivity enhancement over an inverse-gated experiment. This is an approximately 10-fold increase in intensity, based, in theory, on $\gamma(^1H)/\gamma(^{15}N)$ [9]. Thus, one can acquire spectra faster, which is a great benefit, considering the constraints of undergraduate laboratory periods. We took advantage of the speed provided by this sequence and allowed our students to explore the ^1H-coupled ^{15}N spectra as well (Figure 5). By diagramming the splitting pattern the students can explain the appearance of an apparent octet in the ^{15}N spectrum of *cis*-$(^{15}NH_3)_2PtCl_2$ rather than the expected triplet of quartets.

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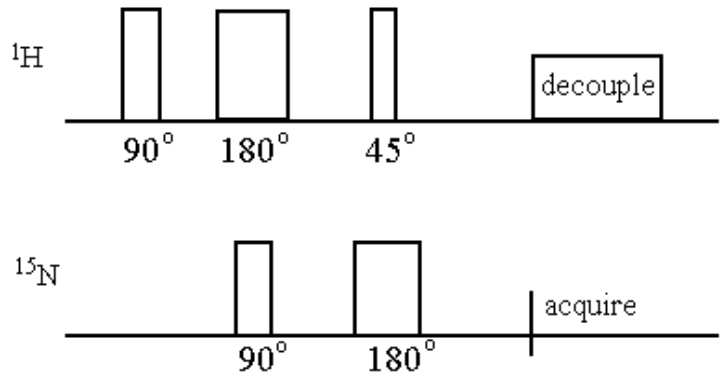

FIGURE 4. DEPT PULSE SEQUENCE FOR ^{15}N SPECTRA.

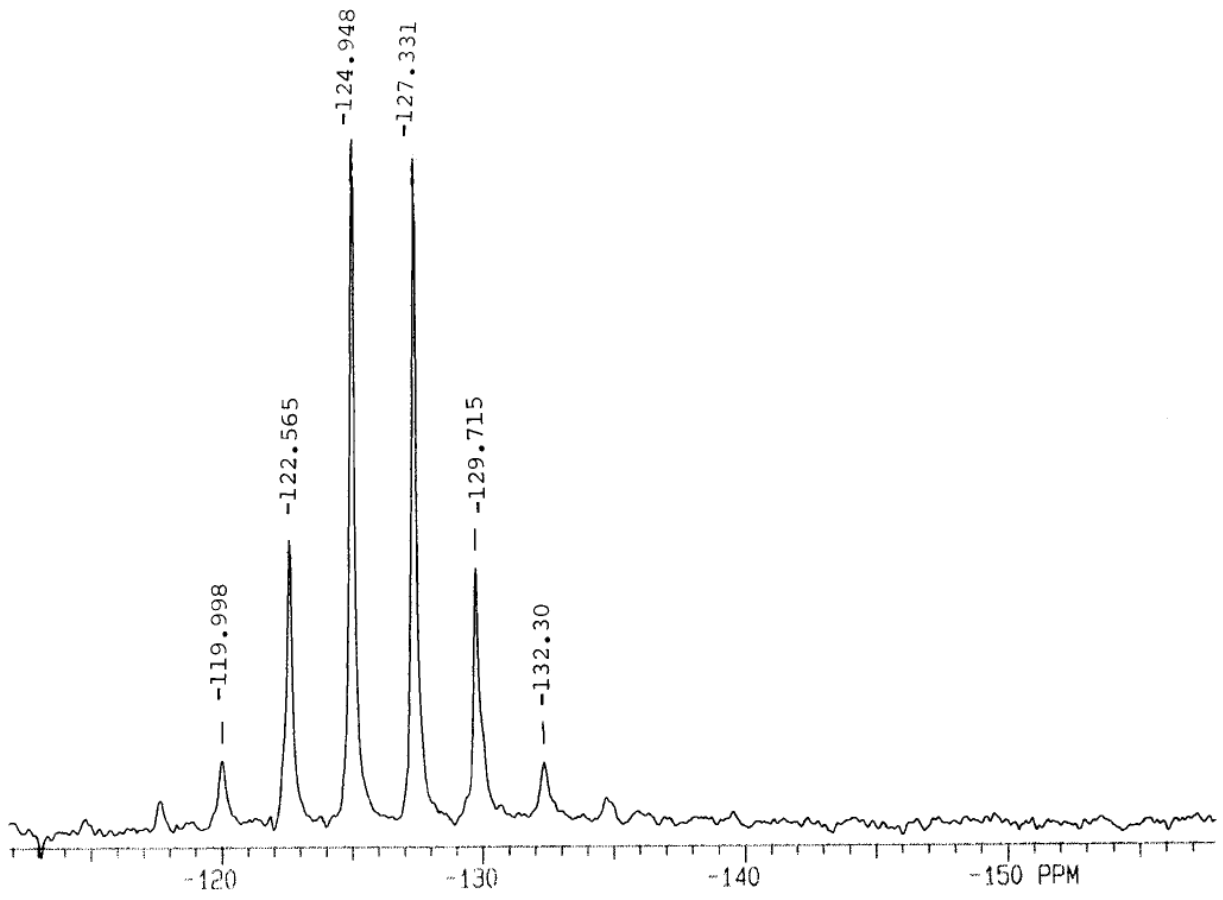

FIGURE 5. ^{1}H-COUPLED ^{15}N NMR *cis*-($^{15}NH_3)_2PtCl_2$, SHOWING $J(^{1}H–^{15}N)$ = 73.6 Hz.

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Spectral simulation provided the students with an appreciation for a technique that is becoming more widespread in the inorganic chemistry community. The procedure allows students to calculate a spectrum of each NMR-active nucleus in the molecule from chemical shifts, coupling-constant values, and line widths.

Conclusions

This experiment demonstrates, in a simple fashion, the use of heteronuclear NMR in inorganic chemistry. Suitable spectra can be obtained in a relatively short period of time. It is also an effective way to introduce students to spectral simulation methods.

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Supplementary Material

Supplementary material (26ga1897.pdf) available includes ^{195}Pt NMR spectra for both labeled and unlabeled *trans*-$(NH_3)_2PtCl_2$, and ^{15}N NMR spectra for *trans*-$(^{15}NH_3)_2PtCl_2$. Simulated ^{195}Pt and ^{15}N NMR spectra for all of the complexes are also included. The laboratory procedure handout we used is also provided.

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