

877. Metal-Metal Interactions in Square-planar Complexes.

By J. R. MILLER.

Ten double complex salts of copper, palladium, and platinum are isomorphous with Magnus's green salt, $[\text{Pt}(\text{NH}_3)_4][\text{PtCl}_4]$. Abnormal colours, associated with metal-metal interaction, are restricted to compounds containing platinum in both anion and cation. It is therefore concluded that adoption of the structure is not dependent on metal-metal interaction, and it is shown on simple electrostatic grounds that the structure would be expected to be very stable.

Some of the theories concerning interactions in these compounds and in the comparable *vic*-dioxime complexes of nickel, palladium, and platinum are discussed, and it is suggested that the interaction could be of an anti-bonding nature.

THE deep green colour of tetrammineplatinum(II) chloroplatinate(II), Magnus's green salt, has attracted attention for many years; the anion is usually red in salts and solutions, the cation colourless, so the green colour of the combined salt points to some abnormality. In 1932, Cox *et al.*¹ showed that the tetragonal crystal contains chains of alternate square-planar anions and cations stacked flat on top of each other with a separation of 3.21 Å; the ionic planes are perpendicular to the *c*-axis. These authors did not make any suggestions about the source of the unusual colour.

In 1951, Yamada² found that the crystal spectrum is very unusual. The absorption maxima of "normal" chloroplatinate(II) and tetrammineplatinum(II) are shifted to lower frequencies and the dichroism is "abnormal," *i.e.*, absorption of light with its electric vector perpendicular to the ionic planes is at a lower frequency and more intense than that of light with electric vector parallel to these planes. One normally finds the reverse situation in the spectra of flat molecules. Yamada concluded that there is some sort of direct interaction between neighbouring platinum atoms.

The first theoretical approach was made by Godycki and Rundle,³ in a study of bis(dimethylglyoximate)nickel(II). This compound has a structure analogous to Magnus's green salt in that planar molecules are stacked in chains, alternate ones being twisted through 90° to allow a close approach of nickel atoms (3.245 Å). These workers sought an explanation of the specificity of dimethylglyoxime as a gravimetric reagent for nickel and for palladium, and, citing the slight pleochroism of the compound, suggested that there is a bonding interaction between the nickel atoms. This would be of sufficient strength to stabilise the simple packing and to cause the low solubility, in contrast to the very soluble copper compound. They suggested that the bonding could arise from partial excitation of 3*d*-electrons to empty 4*p*-orbitals, with pairing of electrons on neighbouring atoms. Thus the hybridisation would be effectively changed from *ds*²*p*³ to *d*²*sp*³. This theory was supported by the discovery that the dichroism is, in fact, abnormal in a way similar to that of Magnus's green salt.⁴ A gold compound, $[\text{Au}(\text{DH})_2][\text{AuCl}_2]$ (DH₂ = dimethylglyoxime), was found to have a structure⁵ analogous to that of bis(dimethylglyoximate)nickel, but was later shown to exhibit normal dichroism.⁶

In 1957, Rundle extended his theory of the interaction by using molecular-orbital theory.⁷ The only essential difference was that a copper(II) compound of this structure would have its odd electron in a *b*_{1g}* orbital (anti-bonding orbital derived from 3*d*_{x²-y²), instead of in a 4*p*-orbital. Thus the odd electron of copper(II) would play no part in the}

¹ Cox, Pinkard, Wardlaw, and Preston, *J.*, 1932, 2527.

² Yamada, *J. Amer. Chem. Soc.*, 1951, **73**, 1579.

³ Godycki and Rundle, *Acta Cryst.*, 1953, **6**, 487.

⁴ Yamada and Tsuchida, *J. Amer. Chem. Soc.*, 1953, **75**, 6351.

⁵ Rundle, *J. Amer. Chem. Soc.*, 1954, **76**, 3101.

⁶ Yamada and Tsuchida, *Bull. Chem. Soc. Japan*, 1957, **30**, 715.

⁷ Rundle, *J. Phys. Chem.*, 1957, **61**, 45.

interaction, and the earlier notion that copper(II) compounds could not adopt this structure was modified.

At about the same time the crystal structure of Magnus's green salt was re-examined,⁸ and a more satisfactory sideways packing of the chains was found. The platinum-platinum distance was corrected to 3.245 Å, exactly the same as the nickel-nickel distance in bis(dimethylglyoximate)nickel.

Sharpe and Wakefield,⁹ in a study of a series of *vic*-dioxime complexes, concluded that the solubility does depend on the nickel-nickel distance; their ligands were all similar and may be presumed to have had little effect on solubility differences. Banks and Barnum,¹⁰ in a similar study, used a very much larger range of ligands and found that these differences had a greater effect on the solubility than did variations in the intermetallic distance.

In a second publication,¹¹ the latter authors described the solution and solid-state spectra of their complexes. They found bands at the long-wavelength ends of the solid-state spectra which were not present in the solution spectra, and they justifiably concluded that these bands were associated with the metal-metal interactions. For an isomorphous series of nickel(II) and palladium(II) complexes, the frequency decreases with decreasing intermetallic distance.

In an attempt to study the effect of increasing intermetallic distance, Yamada and Tsuchida¹² measured the dichroism of alkyl homologues of Magnus's green salt. Only the green compound, $[\text{Pt}(\text{Me}\cdot\text{NH}_2)_4][\text{PtCl}_4]$, shows abnormal dichroism; higher amines give rise to pink compounds with normal dichroism. The result that compounds of this nature with more or less expected colours show normal dichroism is used extensively in the present study to indicate those cases where interaction does not occur.

Finally, two copper compounds must be mentioned which show direct stacking in their structures; in neither case has the dichroism been examined. First, tetramminecopper(II) chloroplatinate(II) is isomorphous with Magnus's green salt and has a slightly shorter *c*-axis;^{13,14} secondly, bis(*N*-methylsalicylaldimine)copper(II) has a structure¹⁵ rather similar to that of bis(dimethylglyoximate)nickel,³ with an interplanar distance of 3.33 Å. It is therefore clear that this type of structure is not confined to ions and molecules of d^8 -configuration, and, under the right conditions, it may be much more general.

The object of this study is to examine some of the factors affecting the occurrence of the Magnus's green salt structure and of metal-metal interaction. Some of the results have already been published,¹⁴ but are repeated for completeness.

RESULTS AND DISCUSSION

The Table lists the important properties of the compounds examined. All substances are tetragonal except (XII). It is clear that all these compounds, except (XII), have unit cells very similar to that of Magnus's green salt. Close examination of absent reflections and of intensities in the powder photographs indicates that the compounds have the same space-group $P4/mnc$, and therefore, by analogy, the anions and cations are stacked in chains with metal-metal distances of $c/2$.

The green compounds (V, VI, and VIII) are known to be abnormally dichroic;^{2,12} it is assumed that (IX) also has this property, but that the remainder are either normal or show very slight interaction. Thus, in the compounds examined, only four of the five containing platinum in both ions show strong interaction; introduction of another metal

⁸ Atoji, Richardson, and Rundle, *J. Amer. Chem. Soc.*, 1957, **79**, 3017.

⁹ Sharpe and Wakefield, *J.*, 1957, 281.

¹⁰ Banks and Barnum, *J. Amer. Chem. Soc.*, 1958, **80**, 3579.

¹¹ Banks and Barnum, *J. Amer. Chem. Soc.*, 1958, **80**, 4767.

¹² Yamada and Tsuchida, *Bull. Chem. Soc. Japan*, 1958, **31**, 813.

¹³ Bukovska and Perai-Koshits, *Kristallografiya*, 1960, **5**, 137.

¹⁴ Miller, *Proc. Chem. Soc.*, 1960, 318.

¹⁵ Lingafelter, Morosin, and Simmons, *Acta Cryst.*, 1960, **13**, 1025.

removes it, without appreciably changing the lattice constants. Close similarity of bond lengths is of common occurrence in corresponding palladium and platinum compounds, and interaction in the all-platinum salts is not sufficient to disturb this.

Substitution of methylamine for ammonia in the salts has no effect on the length of the *c*-axis, indicating that the methyl groups are held in the platinum-nitrogen plane, and that the structure is strong enough to prevent rotation about the platinum-nitrogen bonds. Models show that ethylamine is too large to fit into the plane, and the ethylamine complex has a totally different structure from Magnus's green salt; this fits in well with the pink colour and the "normal" dichroism.¹² (It should be pointed out that the choice of axis in the dichroism measurements on this compound may have been in error, but this would not affect the issue as in any case no large shift was observed.)

Compound (XI) occupies a special place in the scheme. The metal-metal distance is 3.35 Å, only very slightly greater than the longest to be found among the abnormal compounds [3.31 Å in (VIII)], and so, when the small spectroscopic difference between red and green is borne in mind, it may well be that this compound shows a weakly abnormal dichroism. Attempts were made to correlate the interplanar distances with the known dichroism^{2,12} of compounds (V, VI, and VIII), but this was not very informative as the spectra seem to have been measured in slightly different regions. Remarkably, the shift of the perpendicular absorption is greater for the bromide (VIII) than for Magnus's green salt; the former has a longer *c*-axis, and so it seems that the ligand, as well as the metal-metal distance, must have an effect on the interaction. A complete investigation of the crystal spectra of compounds (IX and XI) is required.

The magnetic susceptibility of compound (III) was measured down to liquid-nitrogen temperatures; it obeyed the Curie-Weiss law with a Weiss constant of only 13°, giving $\mu_{\text{eff.}} = 1.90$ B.M. Thus copper-platinum interaction is ruled out in this temperature

Compound		Colour	Expected colour	<i>a</i> (Å)	<i>c</i> (Å)
[Pd(NH ₃) ₄][PdCl ₄]	I	Pink	Pink	8.96	6.49
[Pt(NH ₃) ₄][PtCl ₄]	II	Pink	Pink	8.98	6.45
[Cu(NH ₃) ₄][PtCl ₄]	III	Purple	Purple	9.07	6.46
[Pd(NH ₃) ₄][PtCl ₄]	IV	Pink	Pink	9.06 ¹³	6.43 ¹³
[Pt(NH ₃) ₄][PtCl ₄]	V	Green	Pink	9.00	6.50
[Pt(Me·NH ₃) ₄][PtCl ₄]	VI	Green	Pink	8.96	6.46
[Pt(Me·NH ₃) ₄][PtCl ₄]	VI	Green	Pink	9.03 ⁸	6.50 ⁸
[Pt(Me·NH ₃) ₄][PtCl ₄]	VI	Green	Pink	10.35	6.49
[Pd(NH ₃) ₄][PdBr ₄]	VII	Red	Red	9.32	6.66
[Pt(NH ₃) ₄][PtBr ₄]	VIII	Green	Red	9.32	6.62
[Pt(Me·NH ₃) ₄][PtBr ₄]	IX	Green	Red	10.55	6.61
[Pd(NH ₃) ₄][Pd(SCN) ₄]	X	Pink	Pink	10.60	6.69
[Pt(NH ₃) ₄][Pt(SCN) ₄]	XI	Red	Orange	10.62	6.70
[Pt(Et·NH ₂) ₄][PtCl ₄]	XII	Pink	Pink	Not tetragonal	

range; it must, however, be remembered that the odd electron is in the b_{1g}^* -orbital, which is not suitable for interaction, being localised in the copper-ammonia plane. If a complex ion of cobalt(II), for example, were found in a similar environment, there would be a good chance of finding anomalous magnetic behaviour, as the odd electron would lie in the all-important a_{1g}^* -orbital ($3d_z^2$ with some intermixing of $4s$).

It has been suggested that the metal-metal interaction is responsible for the adoption of this structure, and for the low solubility of Magnus's green salt.^{3,8} Whilst no quantitative solubility measurements have been carried out, it is worth noting that the pink compounds (I-IV) are insoluble, whilst the green compounds (VI and IX) are moderately soluble in water (giving red solutions). Solubility depends on the difference between lattice energy and heats of solvation. By applying the relationship,¹⁶ $U_c = 2Nz^2e^2 \ln 2/d$, for the Coulombic lattice energy of a chain of positive and negative charges,

¹⁶ Moelwyn-Hughes, "Physical Chemistry," Pergamon Press, London, 1957.

values of U_c from -575 to -550 kcal./mole are obtained as d varies from 3.20 to 3.35 Å. These are in all probability lower than the true lattice energies, as sideways attractions between charges have been neglected. They are much higher than those of the alkali-metal halides, and somewhat smaller than those of the insoluble oxides and sulphides of bivalent metals.¹⁷ Since the flat complex ions are considerably larger than alkaline-earth, oxide, or sulphide ions, they would be expected to have smaller heats of solvation. It follows that low solubility is to be expected, and that the Magnus's green salt structure is particularly stable, regardless of the existence of any metal-metal interactions.

Theory of Interaction.—There are three types of compound which form "direct-stacking" structures. First, there are the well-established organic addition complexes such as quinhydrone, which consists of chains of alternate quinone and quinol molecules stacked in parallel,¹⁸ with an interplanar spacing of 3.16 Å. The dichroism is strongly abnormal,¹⁹ and the properties can be readily interpreted as due to co-ordination of the quinol π -electrons to the empty π -orbitals of the quinone. The fact that hexamethylbenzene,²⁰ for example, does not form quite such a simple structure may be put down to repulsion of the π -electrons.

The second type of compound consists of the *vic*-dioximates of nickel, palladium, and platinum, and bis-(*N*-methylsalicylaldiminato)copper(II). Abnormal dichroism is apparent in the nickel and platinum dimethylglyoxime complexes.⁴ This cannot be ascribed to a charge-transfer mechanism as in quinhydrone, because neighbouring molecules are identical. In Rundle's theory⁷ interaction between only two molecules is considered, but this theory may be readily extended to cover a chain of n molecules. The a_{1g}^* - and the $a_{2u}(4p_z)$ -orbitals each form a bonding and an anti-bonding band; those from the a_{1g}^* -orbitals are fully occupied, and without further treatment it can be seen that the net result would be anti-bonding. Rundle suggested that configurational interaction between the anti-bonding a_{1g}^* - and the bonding a_{2u} -bands would give the modification required to lower the energy. Such interaction would presumably give a function which allowed the highest-energy electrons considerable freedom of movement along the chain.

An alternative presentation is to allow the a_{1g}^* - and the a_{2u} -orbitals on one molecule to form two equivalent hybrids; each would have a large lobe along the axis. When a chain of n molecules is formed, the hybrids give rise to two non-bonding orbitals, $n - 1$ equivalent bonding and $n - 1$ equivalent anti-bonding orbitals. If n is large, the non-bonding orbitals, which are at each end of the chain, may be neglected. The electrons fill the bonding orbitals and half-occupy the non-bonding orbitals, and so the overall effect would be bonding.

There is the further possibility that the anti-bonding band from a_{1g}^* can reach above the b_{1g}^* level, which is intermediate between a_{1g}^* and a_{2u} in an isolated molecule. In this case, half of the axial electrons would be forced into the b_{1g}^* -orbitals in the planes of the molecules, while the other half would be stabilised along the axis.

Banks and Barnum¹¹ attributed the band in the solid-state spectra of their dioxime complexes to a transition from a_{1g}^* to b_{1g}^* . In order to account for the *drop* in frequency with decreasing metal-metal distance, one must assume that the gap between a_{1g}^* and b_{1g}^* becomes smaller as the metal-metal distance decreases. This could come about very simply by interaction of the a_{1g}^* -orbitals alone, the a_{2u} -orbitals being neglected; these orbitals would interact to form an energy band, which would have an overall anti-bonding effect, since all levels are occupied. In such a case, the structure would be formed in spite of the interaction, rather than on account of it.

By combining the two extremes, of interaction between the a_{1g}^* -orbitals alone and of

¹⁷ Waddington, "Advances in Inorganic Chemistry and Radiochemistry," Academic Press, 1959, Vol. I.

¹⁸ Matsuda, *Bull. Chem. Soc. Japan*, 1958, **31**, 611.

¹⁹ Nakamoto, *J. Amer. Chem. Soc.*, 1952, **74**, 1739.

²⁰ Robertson, "Organic Crystals and Molecules," Cornell Univ. Press, 1953.

hybridisation of a_{1g}^* and a_{2u} , it is seen that the amount of bonding or anti-bonding would depend on the exact amount of mixing of the a_{2u} - into the a_{1g}^* -orbitals.

Compounds with the composition of Magnus's green salt form the third class. In this case the co-ordination theory applicable to quinhedrone is equivalent to the molecular-orbital theory, as neighbouring species are not identical. Co-ordination could be considered to occur from the a_{1g}^* of the anion to the a_{2u} of the cation. The exact reason why palladium compounds do not seem to have this interaction must lie in the relative sizes of the orbitals concerned, or it may be that platinum can use its $4f$ -orbitals to advantage.

The conclusion to be drawn from this work is that metal-metal interaction cannot be held responsible for the adoption of the Magnus's green salt structure, but rather that such interaction can occur in certain compounds which crystallise in this way. The Magnus's green salt structure is an electrostatically favourable one for doubly-charged square-planar ions to adopt, without the influence of these interactions which at present seem to be limited to platinum-platinum salts with intermetallic distances less than 3.35 Å. Present indications are that several other materials crystallise in slightly deformed versions of the Magnus's green salt lattice, and this can be explained by repulsion of π - and a_{1g}^* -electrons. It is suggested that the analogous structures of *vic*-dioxime complexes may be explained in terms of favourable packing, and that when metal-metal interaction occurs, the possibility of its being anti-bonding should not be excluded.

EXPERIMENTAL

Compounds were obtained as crystalline precipitates by mixing stoichiometric amounts of the appropriate ions in aqueous solution. The solutions were cooled to 0° before mixing to avoid formation of monomers such as dichlorodiamminepalladium and to discourage exchanges of ligand between different metal atoms. Acid was added, where it did not react with the cation, as this is reputed to encourage the formation of green compounds.¹ The analyses are listed.

Tetramminepalladium chloropalladate(II). Found: Pd, 49.8; Cl, 32.9. Calc. for $H_{12}Cl_4N_4Pd_2$: Pd, 50.3; Cl, 33.6%.

Tetrammineplatinum chloropalladate(II). Found: Pd, 20.4; Cl, 27.4. Calc. for $H_{12}Cl_4N_4PdPt$: Pd, 20.8; Cl, 27.7%.

Tetramminepalladium chloroplatinate(II). Found: Pd, 20.6; Cl, 27.6%.

Tetramminecopper chloroplatinate(II). Found: N, 12.3; Cl, 30.4. Calc. for $H_{12}Cl_4CuN_4Pt$: N, 11.95; Cl, 30.25%.

Tetrammineplatinum chloroplatinate(II). Found: Cl, 23.5. Calc. for $H_{12}Cl_4N_4Pt_2$: Cl, 23.6%.

Tetramminepalladium bromopalladate(II). Found: Pd, 34.8; Br, 53.4. Calc. for $H_{12}Br_4N_4Pd_2$: Pd, 35.5; Br, 53.2%.

Tetrammineplatinum bromoplatinate(II). Found: Br, 40.8. Calc. for $H_{12}Br_4N_4Pt_2$: Br, 41.1%.

Tetramminepalladium thiocyanatopalladate(II). Found: Pd, 40.8; SCN, 45.0. Calc. for $C_4H_{12}N_8Pd_2S_4$: Pd, 41.5; SCN, 45.2%.

Tetra(methylamine)platinum chloroplatinate(II). Found: C, 6.7; H, 3.1; N, 9.05; Cl, 21.6. Calc. for $C_4H_{20}N_4Cl_4Pt_2$: C, 7.3; H, 3.1; N, 8.5; Cl, 21.6%.

Tetra(methylamine)platinum bromoplatinate(II). Found: C, 5.1; H, 2.4; N, 6.1; Br, 38.4. $C_4H_{20}Br_4N_4Pt_2$ requires C, 5.8; H, 2.4; N, 6.7; Br, 38.3%.

Tetra(ethylamine)platinum chloroplatinate(II). Found: C, 13.0; H, 3.3; N, 8.1; Cl, 19.9. Calc. for $C_8H_{28}Cl_4N_4Pt_2$: C, 13.5; H, 4.0; N, 7.9; Cl, 19.9%.

X-Ray Powder Photographs.—These were taken in Unicam 19 cm. cameras, with Cu- $K\alpha$ radiation. The finely powdered samples were packed into thin-walled Pyrex glass capillaries, which were sealed with picein wax. The $\sin^2 \theta$ values and the indexing are tabulated. The unit cell dimensions are listed in the discussion section.

Magnetic Susceptibility.—The susceptibility of $[Cu(NH_3)_4][PtCl_4]$ was measured by the Gouy method in the temperature range 83—293° K. It obeyed the equation $\chi_M = \mu_{eff}^2/2.84^2(T + 13)$, where $\mu_{eff} = 1.90$ B.M.

Int.	$\sin^2 \theta$ (obs.)	$\sin^2 \theta$ (calc.)	hkl	Int.	$\sin^2 \theta$ (obs.)	$\sin^2 \theta$ (calc.)	$\sin^2 \theta$ (B)	hkl	Int.	$\sin^2 \theta$ (obs.)	$\sin^2 \theta$ (calc.)	hkl
	[Pd(NH ₃) ₄][PdCl ₄]				[Cu(NH ₃) ₄][PtCl ₄]					[Pd(NH ₃) ₄][Pd(SCN) ₄]		
vs	0-0144	0-0148	110	s	0-0290	0-0289	0-0290	200	m	0-0953	0-0952	330
s	0-0293	0-0295	200	w	0-0500	0-0504	0-0506	211		0-0954	0-0954	222
w	0-0501	0-0510	211	s	0-0568	0-0570	0-0575	002	s	0-1062	0-1058	420
s	0-0559	0-0564	002	vs	0-0719	0-0715	0-0720	112		0-1060	0-1060	312
s	0-0706	0-0712	112	mw	0-0795	0-0793	0-0796	310	ms	0-1377	0-1378	510
s	0-0735	0-0738	310	s	0-0862	0-0859	0-0865	202	m	0-1483	0-1483	402
ms	0-0856	0-0859	202	w	0-1083	0-1082	0-1085	321	m	0-1593	0-1589	332
ms	0-0874	0-0879	311	m	0-1157	0-1157	0-1159	400	ms	0-1689	0-1693	422
ms	0-1176	0-1180	400	ms	0-1297	0-1293	0-1299	312				
ms	0-1296	0-1302	312		0-1304	0-1301	0-1301	330				
w	0-1325	0-1328	350	mw	0-1369	0-1372	0-1375	411	vs	0-0105	0-0106	110
ms	0-1469	0-1475	420	m	0-1451	0-1446	0-1448	420	vw	0-0188	0-0185	101
ms	0-1738	0-1744	402	m	0-1729	0-1727	0-1734	402	s	0-0211	0-0211	200
mw	0-1859	0-1892	332	m	0-1881	0-1871	0-1879	532	w	0-0423	0-0422	220
mw	0-1918	0-1918	510	w	0-1949	0-1850	0-1854	431	vs	0-0529	0-0528	310
	[Pd(NH ₃) ₄][PtCl ₄]				[Pt(NH ₃) ₄][PtCl ₄]					0-0529	0-0529	002
vs	0-0144	0-0147	110	ms	0-2022	0-2016	0-2024	422	mw	0-0634	0-0635	112
mw	0-0211	0-0214	101		0-2022	0-2027	0-2027	511	vw	0-0822	0-0818	321
m	0-0290	0-0293	200	$\sin^2 \theta (B)$ values are calculated from the unit cell in ref. 13.					w	0-0844	0-0844	400
m	0-0561	0-0562	002	Int.	$\sin^2 \theta$ (obs.)	$\sin^2 \theta$ (calc.)	hkl		mw	0-0951	0-0950	330
m	0-0708	0-0708	112							0-0951	0-0951	222
m	0-0729	0-0734	310	s	0-0135	0-0137	110		s	0-1059	0-1055	420
vw	0-0798	0-0801	301	w	0-0201	0-0202	101		m	0-1379	0-1372	510
m	0-0860	0-0856	202	ms	0-0272	0-0274	200		w	0-1591	0-1584	422
w	0-1189	0-1174	400	w	0-0345	0-0343	210		w	0-1700	0-1688	440
mw	0-1296	0-1296	312	s	0-0476	0-0477	211		mw	0-1793	0-1793	530
mw	0-1468	0-1468	420	m	0-0534	0-0536	002		mw	0-1899	0-1899	600
mw	0-1736	0-1738	402	ms	0-0673	0-0673	112		mw	0-1901	0-1901	512
w	0-1894	0-1883	332	ms	0-0687	0-0685	310		mw	0-2115	0-2110	620
m	0-2036	0-2030	422		0-0817	0-0810	202			0-2116	0-2116	004
w	0-2491	0-2496	530	ms	0-0817	0-0819	311					
	[Pt(NH ₃) ₄][PdCl ₄]				[Pt(NH ₃) ₄][PdBr ₄]					[Pt(MeNH ₃) ₄][PtCl ₄]		
vs	0-0143	0-0148	110	s	0-0135	0-0137	110		vs	0-0109	0-0111	110
s	0-0286	0-0296	200	w	0-0201	0-0202	101		s	0-0220	0-0222	200
vw	0-0366	0-0370	210	ms	0-0272	0-0274	200		m	0-0444	0-0444	220
w	0-0517	0-0513	211	w	0-0345	0-0343	210		s	0-0558	0-0555	310
s	0-0565	0-0572	002	s	0-0476	0-0477	211		m	0-0675	0-0675	002
s	0-0719	0-0720	112	m	0-0534	0-0536	002		ms	0-0675	0-0675	112
s	0-0741	0-0740	310	ms	0-0673	0-0673	112		vw	0-0691	0-0696	311
m	0-0869	0-0868	202	ms	0-0687	0-0685	310		m	0-0783	0-0786	202
w	0-1182	0-1184	400		0-0817	0-0810	202		mw	0-0886	0-0888	400
ms	0-1312	0-1312	312		0-0819	0-0819	311		s	0-1003	0-0999	330
m	0-1481	0-1480	420		0-1096	0-1096	400			0-1008	0-1008	222
mw	0-1759	0-1756	402		0-1221	0-1221	312		vs	0-1114	0-1110	420
w	0-1926	0-1924	510		0-1371	0-1370	420			0-1119	0-1119	312
m	0-2054	0-2052	422		0-1633	0-1632	402		ms	0-1447	0-1442	510
w	0-2498	0-2516	530		0-1702	0-1700	412			0-1452	0-1452	402
	[Pt(NH ₃) ₄][PtBr ₄]				[Pt(NH ₃) ₄][PtBr ₄]					[Pt(MeNH ₃) ₄][PtBr ₄]		
vs	0-0143	0-0148	110	vs	0-0132	0-0137	110		vs	0-0109	0-0111	110
s	0-0286	0-0296	200	vw	0-0201	0-0204	101		s	0-0220	0-0222	200
vw	0-0366	0-0370	210	s	0-0272	0-0274	200		ms	0-0444	0-0444	220
w	0-0517	0-0513	211	vw	0-0337	0-0342	210		m	0-0558	0-0555	310
s	0-0565	0-0572	002	mw	0-0475	0-0478	211		s	0-0675	0-0675	112
s	0-0719	0-0720	112	s	0-0539	0-0542	002		vw	0-0691	0-0696	311
s	0-0741	0-0740	310	vs	0-0681	0-0685	310		m	0-0783	0-0786	202
m	0-0869	0-0868	202	s	0-0815	0-0816	202		mw	0-0886	0-0888	400
w	0-1182	0-1184	400	m	0-1094	0-1096	400		m	0-1003	0-0999	330
ms	0-1312	0-1312	312	vs	0-1221	0-1227	312		vs	0-1114	0-1110	420
m	0-1481	0-1480	420	vw	0-1297	0-1300	411			0-1119	0-1119	312
mw	0-1759	0-1756	402	m	0-1371	0-1370	420		ms	0-1447	0-1442	510
w	0-1926	0-1924	510	m	0-1638	0-1638	402			0-1452	0-1452	402
m	0-2054	0-2052	422	vw	0-1712	0-1706	412		m	0-1564	0-1563	332
w	0-2498	0-2516	530		0-1712	0-1712	430		s	0-1676	0-1674	422
	[Pt(NH ₃) ₄][PtBr ₄]				[Pt(NH ₃) ₄][PtBr ₄]				w	0-1779	0-1775	440
vs	0-0143	0-0148	110		0-1712	0-1712	430		mw	0-1889	0-1886	530
s	0-0286	0-0296	200		0-1712	0-1712	430		m	0-1997	0-1997	600
vw	0-0366	0-0370	210		0-1712	0-1712	430		ms	0-2008	0-2006	512
w	0-0517	0-0513	211		0-1712	0-1712	430			0-2783	0-2783	622
s	0-0565	0-0572	002		0-1712	0-1712	430					
s	0-0719	0-0720	112		0-1712	0-1712	430					
s	0-0741	0-0740	310		0-1712	0-1712	430					
m	0-0869	0-0868	202		0-1712	0-1712	430					
w	0-1182	0-1184	400		0-1712	0-1712	430					
ms	0-1312	0-1312	312		0-1712	0-1712	430					
m	0-1481	0-1480	420		0-1712	0-1712	430					
mw	0-1759	0-1756	402		0-1712	0-1712	430					
w	0-1926	0-1924	510		0-1712	0-1712	430					
m	0-2054	0-2052	422		0-1712	0-1712	430					
w	0-2498	0-2516	530		0-1712	0-1712	430					
	[Pt(NH ₃) ₄][PtBr ₄]				[Pt(NH ₃) ₄][PtBr ₄]					[Pt(MeNH ₃) ₄][PtBr ₄]		
vs	0-0143	0-0148	110		0-1712	0-1712	430		vs	0-0105	0-0107	110
s	0-0286	0-0296	200		0-1712	0-1712	430		vw	0-0189	0-0189	101
vw	0-0366	0-0370	210		0-1712	0-1712	430		m	0-0212	0-0214	200
w	0-0517	0-0513	211		0-1712	0-1712	430		w	0-0425	0-0427	220
s	0-0565	0-0572	002		0-1712	0-1712	430		s	0-0541	0-0544	002
s	0-0719	0-0720	112		0-1712	0-1712	430		vw	0-0614	0-0617	301
s	0-0741	0-0740	310		0-1712	0-1712	430		m	0-0647	0-0651	112
m	0-0869	0-0868	202		0-1712	0-1712	430		s	0-0756	0-0758	202
w	0-1182	0-1184	400		0-1712	0-1712	430		w	0-0852	0-0854	400
ms	0-1312	0-1312	312		0-1712	0-1712	430			0-0963	0-0961	330
m	0-1481	0-1480	420		0-1712	0-1712	430			0-0971	0-0971	222
mw	0-1759	0-1756	402		0-1712	0-1712	430			0-1068	0-1068	420
w	0-1926	0-1924	510		0-1712	0-1712	430					