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Neighbouring group participation of platinum(II) in the substitution of the α-halogen in complexes [PtI(CHXSiMe$_3$)(*R*,*R*-chiraphos)] [X = Cl or Br; chiraphos = 2,3-bis(diphenylphosphino)butane] by iodide. An example of an S$_N$1 substitution at sp^3 carbon with inversion of configuration†

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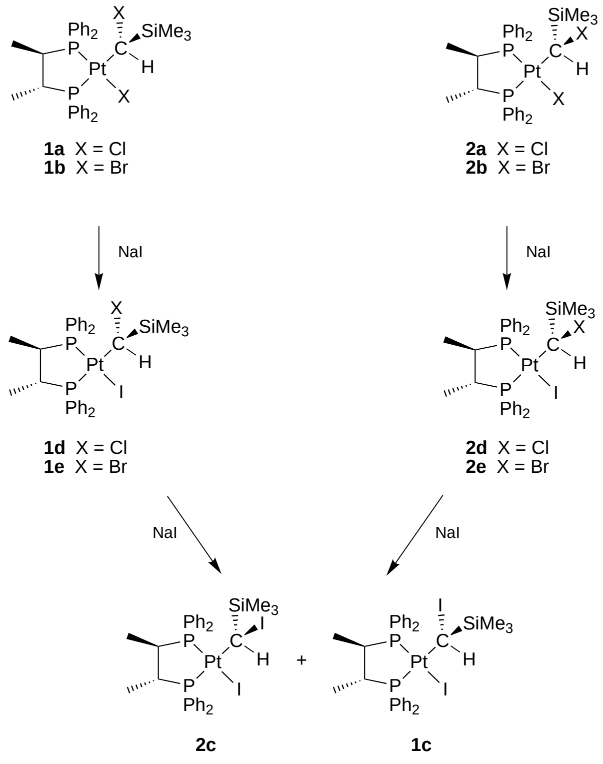
The complexes [PtX(*R*-CHXSiMe$_3$)(*R*,*R*-chiraphos)] and [PtX(*S*-CHXSiMe$_3$)(*R*,*R*-chiraphos)] [X = Cl or Br; chiraphos = 2,3-bis(diphenylphosphino)butane], as single diastereomers, reacted with NaI in CH$_3$CN to give [PtI(CHISiMe$_3$)(*R*,*R*-chiraphos)] as an equilibrium mixture of diastereomers. The reactions were monitored by ^{31}P NMR spectroscopy and shown to occur in two stages in each case: a rapid substitution at platinum to give [PtI(*R*-CHXSiMe$_3$)(*R*,*R*-chiraphos)] and [PtI(*S*-CHXSiMe$_3$)(*R*,*R*-chiraphos)] (X = Cl or Br) as intermediates, followed by much slower substitution at carbon to give the diiodo products. Attempts to isolate pure monoiodo intermediates by treatment of [PtX(*R*/*S*-CHXSiMe$_3$)(*R*,*R*-chiraphos)] (X = Cl or Br) with 1 equivalent of NaI led to products contaminated by the diiodo complexes. Thus the monoiodo complexes were generated *in situ* and the kinetics of the substitutions at carbon was investigated by ^{31}P NMR spectroscopy or polarimetry. The substitutions at carbon are first-order reactions; the rates for the [PtI(*R*-CHXSiMe$_3$)(*R*,*R*-chiraphos)] (the more stable diastereomer) are slower than for [PtI(*S*-CHXSiMe$_3$)(*R*,*R*-chiraphos)] by factors of *ca.* 100 for X = Cl and *ca.* 40 for X = Br. For the most reactive complex [PtI(*S*-CHBrSiMe$_3$)(*R*,*R*-chiraphos)] inversion of configuration upon substitution was detected, the extent of which was extrapolated to be initially *ca.* 95%. Mechanisms involving platinum–carbene intermediates are invoked in order to explain the kinetic and stereochemical results.

Metal alkyls having a chiral centre at the α-carbon are valuable for organometallic mechanistic studies.[1] We[2,3] and others[4,5] have shown that the insertion of carbenes, derived from RCHN$_2$ (*e.g.* R = CO$_2$Et or SiMe$_3$), into Pt–X (X = Cl, Br or I) bonds provides access to complexes containing the chiral PtCHXR group and when the ancillary ligands on platinum are optically active, single diastereoisomers can be obtained. It is of fundamental interest to determine the effect of platinum(II) on the mechanism of substitution of a halogen atom on carbon. Moreover, if the halogen atoms on the α-carbon atom could be substituted stereospecifically, then we would have a general route to α-chiral platinum complexes. Halogen-substitution reactions of [PtX(*R*/*S*-CHXSiMe$_3$)(*R*,*R*-chiraphos)] [X = Cl and Br; chiraphos = 2,3-bis(diphenylphosphino)butane] by iodide to give [PtI(*R*/*S*-CHISiMe$_3$)(*R*,*R*-chiraphos)] were chosen for detailed mechanistic study because the absolute configuration and the configurational stability of the reactants and products have previously been determined.[2]

Results

The reactions of the diastereomeric dichloro complexes **1a** and **2a**, and dibromo complexes **1b** and **2b**, with NaI in MeCN were followed by ^{31}P NMR spectroscopy and found to proceed according to Scheme 1. In each case it was observed that the halogen on the platinum was displaced rapidly (with precipitation of NaCl or NaBr) to give **1d**, **2d**, **1e** and **2e** (see Table 1 for data) and this was followed by slower displacement of halogen on carbon to give the expected diiodo products **1c** and **2c**.



Scheme 1

Since the substitution of the halogen on the α-carbon was the focus of our attention, we attempted to isolate the mixed-halogen complexes **1d-1e** and **2d-2e**. However, we were unable

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† *Supplementary data available* (No. SUP 57301, 19 pp.): plots for obtaining the values of the rate constants *k* given in Table 2. See Instructions for Authors, *J. Chem. Soc.*, *Dalton Trans.*, 1997, Issue 1.

Table 1 Phosphorus-31 NMR data[a]

Complex	$\delta(P_A)$	$^1J(PtP_A)$	$\delta(P_B)$	$^1J(PtP_B)$	$^2J(P_AP_B)$	Ratio[b]
1a	42.92	4034	44.00	1794	13	10
2a[c]	44.35	4116	46.27	1783	13	
1b[c]	43.18	4000	42.27	1818	13	5
2b	45.28	4053	45.44	1812	12	
1c[c]	41.40	3843	38.84	1839	12	5
2c	43.50[d]	3906	42.85	1838	12	
1d	41.30	3897	40.90	1766	13	
2d	43.10	3997	43.20	1752	13	
1e	41.40	3844	39.96	1800	12	
2e	43.00	3987	41.40	1861	13	

[a] Spectra (81 MHz) measured in MeCN at 22 °C unless otherwise stated. Chemical shifts (δ) in ppm (± 0.1) to high frequency of 85% H_3PO_4. Coupling constants (*J*) in Hz (± 3). P_A is *trans* to the halogen and P_B *trans* to the carbon. [b] Equilibrium ratio.[2] [c] Crystal structure determined.[2] [d] This shift was incorrectly given in ref. 2.

Table 2 Kinetic data

Entry	Complex	Method	$[I^-]$/M	Ionic strength/M	k^a/s^{-1}
1	**1d**	NMR	0.11	0.44[b]	$6.0(1) \times 10^{-6}$
2			0.22	0.44[b]	$6.1(2) \times 10^{-6}$
3			0.44	0.44	$5.9(2) \times 10^{-6}$
4	**2d**	Polarimetry	0.30	0.30	$4.0(1) \times 10^{-4}$
5			0.40	0.40	$3.8(1) \times 10^{-4}$
6			0.40	0.40	$4.4(1) \times 10^{-4}$
7			0.50	0.50	$4.4(1) \times 10^{-4}$
8	**2e**	Polarimetry	0.10	0.10	$3.5(1) \times 10^{-3}$
9			0.20	0.20	$4.6(2) \times 10^{-3}$
10			0.20	0.20	$5.1(4) \times 10^{-3}$
11			0.20	0.40[c]	$3.7(1) \times 10^{-3}$
12			0.30	0.30	$4.7(2) \times 10^{-3}$
13			0.40	0.40	$5.5(4) \times 10^{-3}$
14			0.40	0.40	$4.6(4) \times 10^{-3}$
15			0.50	0.50	$3.7(4) \times 10^{-3}$

[a] The figure in parenthesis is the estimated error in the final figure. [b] The ionic strength is [NaI] + [$NaBF_4$]. [c] The ionic strength is [NaI] + [$LiClO_4$].

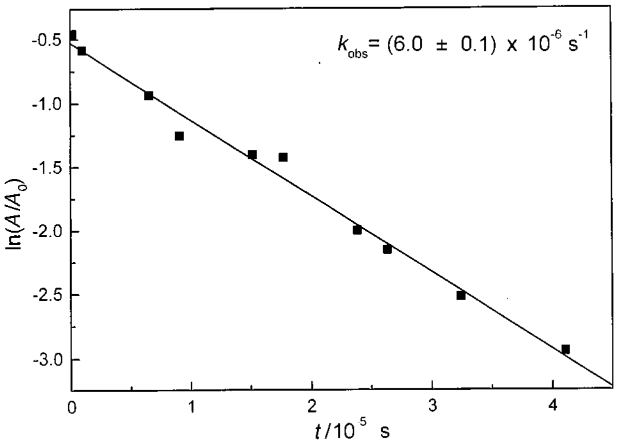


Fig. 1 Plot of ln(A/A_0) against time *t* where *A* is the concentration, as determined by NMR spectroscopy, of [PtI(*R*-CHClSiMe$_3$)(*R*,*R*-chiraphos)] **1d** and A_0 the initial concentration of **1d** (under the conditions of entry 1 in Table 2)

to obtain pure products, *e.g.* the products obtained from solutions of the chloroiodo complexes **1d** and **2d** were found to contain 10–20% of the diiodo complexes **1c** and **2c**. Hence for the kinetic studies below the mixed-halogen complexes were generated *in situ*.

Substitution of chloride in [PtI(*R*-CHClSiMe$_3$)(*R*,*R*-chiraphos)] 1d by iodide

This substitution was sufficiently slow to be followed accurately by ^{31}P NMR spectroscopy. The reactions were carried out with initial ratios of NaI to platinum complex of 5 : 1, 10 : 1 and 20 : 1 with the ionic strength kept constant at 0.44 M using $LiBF_4$ as background electrolyte. The ^{31}P NMR spectra were measured over a period of 2 weeks and from the integrals of the signals the rate constants were determined (see Fig. 1 for an example); they were of the order of 6×10^{-6} s^{-1} and independent of concentration of iodide (see Table 2). The products **1c** and **2c** were obtained as an equilibrium mixture, as expected since epimerisation of **1c** and **2c** occurs much more rapidly (*k* of the order of 2×10^{-3} s^{-1})[2] than chloride substitution.

Substitution of [PtI(*S*-CHClSiMe$_3$)(*R*,*R*-chiraphos)] 2d by iodide

This substitution was too fast for the kinetics to be measured accurately by ^{31}P NMR spectroscopy and therefore polarimetry was used. The reactions were carried out in the presence of a large excess of NaI (>20 : 1) and the optical measurements were begun 4 min after mixing the NaI solution with complex **2a** to allow for essentially complete substitution of the chloride on platinum to have taken place (as established by ^{31}P NMR spectroscopy, see above). Values were recorded over *ca.* 2 h and a typical run is plotted in Fig. 2. At the end of each run it was noticed that the solutions in the cells were cloudy due to the precipitation of NaCl and this may be a source of some error in these measurements. The observed rate constants (see Table 2), calculated from the exponential fits (*e.g.* Fig. 2), were independent of the concentration of iodide and of the order of 4×10^{-4} s^{-1}. Once again the products **1c** and **2c** were obtained as an equilibrium mixture because the substitution rate is an order of magnitude slower than the rate of epimerisation of **1c** and **2c**.

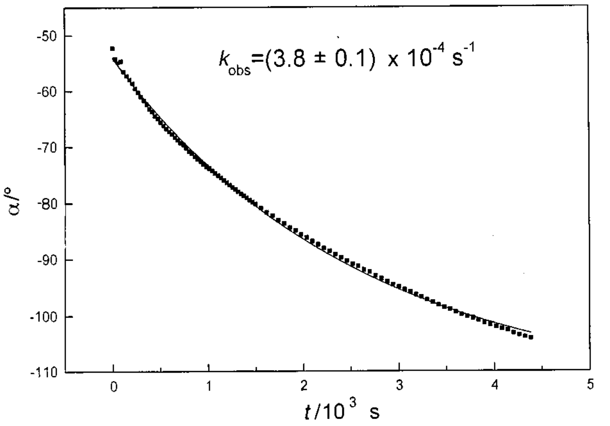


Fig. 2 Exponential fit for the variation of angle of rotation α with time t upon treatment of [PtI(S-CHClSiMe$_3$)(R,R-chiraphos)] **2d** with NaI (under the conditions of entry 5 in Table 2)

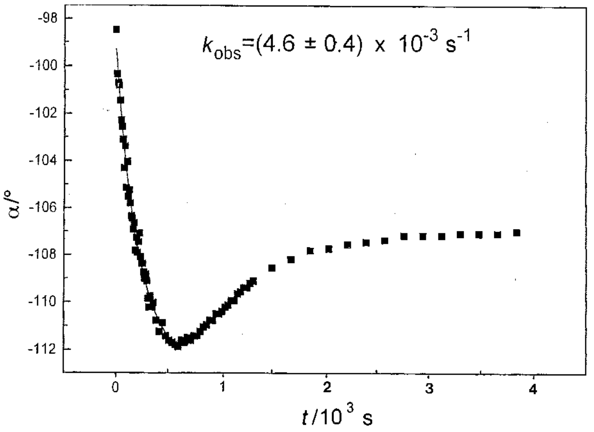


Fig. 3 Variation of angle of rotation α with time t obtained upon treatment of [PtI(S-CHBrSiMe$_3$)(R,R-chiraphos)] **2e** with NaI (under the conditions of entry 14 in Table 2) showing the two distinct exponential processes (see Results section)

Substitution of [PtI(R-CHBrSiMe$_3$)(R,R-chiraphos)] 1e by iodide

This substitution was too fast for the kinetics to be measured accurately by ^{31}P NMR spectroscopy and so we attempted to use polarimetry in a similar manner to the experiment with complex **2d** above in the presence of varying amounts of iodide. Despite repeated experiments the curves obtained defied simple analysis. The NMR spectra showed that the reaction followed the expected course but the assumption that substitution at the Pt is complete within 4 min of mixing in this case is not valid since *ca.* 10% of dibromo complex **1b** remained even after 10 min. The rate of substitution at carbon was estimated from the NMR spectra to be of the order of 1×10^{-4} s^{-1}. Though it was not possible to determine the order of the reaction with the accuracy of the other substitutions discussed here, it was clear from the NMR studies that the concentration of iodide did not have a large effect.

Substitution of [PtI(S-CHBrSiMe$_3$)(R,R-chiraphos)] 2e by iodide

These reactions were carried out with initial ratios of NaI to platinum complex ranging from 8:1 to 40:1 and followed by polarimetry; the optical measurements were begun 4 min after mixing the NaI solution with complex **2b** to allow for essentially complete substitution of the bromide on platinum to have taken place (as established by ^{31}P NMR spectroscopy, see above). A plot of the optical rotation as a function of time shows that two distinct processes are taking place. For example Fig. 3 shows a typical plot for which the first process (from 0 to *ca.* 500 s) has a rate of the order of 5×10^{-3} s^{-1} and the second a rate of the order of 2.5×10^{-3} s^{-1}. The first process is assigned to substitution of the bromine on carbon by iodine and is independent of iodide concentration (see Table 2). The second process corresponds to the epimerisation rate for **1c** ↔ **2c**, previously measured[2] in MeCN to be of the order of 2×10^{-3} s^{-1}. This proposal is supported by the following high-field NMR experiment. Complex **2b** was dissolved in NaI-saturated CD$_3$CN and ^{31}P spectra (202 MHz) recorded at intervals (see Fig. 4). Under these conditions the bromine on the platinum in **2b** is completely substituted within 3 min to give **2e** and **1c**. Over the following 300 s the signals for **2e** vanish. The only change over the following 60 min is an increase in the amount of **2c** relative to **1c**, *i.e.* epimerisation, in agreement with the polarimetry results (see above). The intensity of the signals for **2c** relative to **1c** increase from a ratio of *ca.* 1:10 (after 6 min) to the equilibrium proportion of 1:5 (after 60 min) and therefore the reaction is under kinetic control. By extrapolation of the data from the integrals to zero time the initial ratio was estimated to be *ca.* 1:18, which corresponds to *ca.* 95% inversion at the α-carbon. To recapitulate, inversion occurs at the α-carbon, since **2e** (with S configuration at the α-carbon) gives preferentially **1c** (with R configuration at the α-carbon).

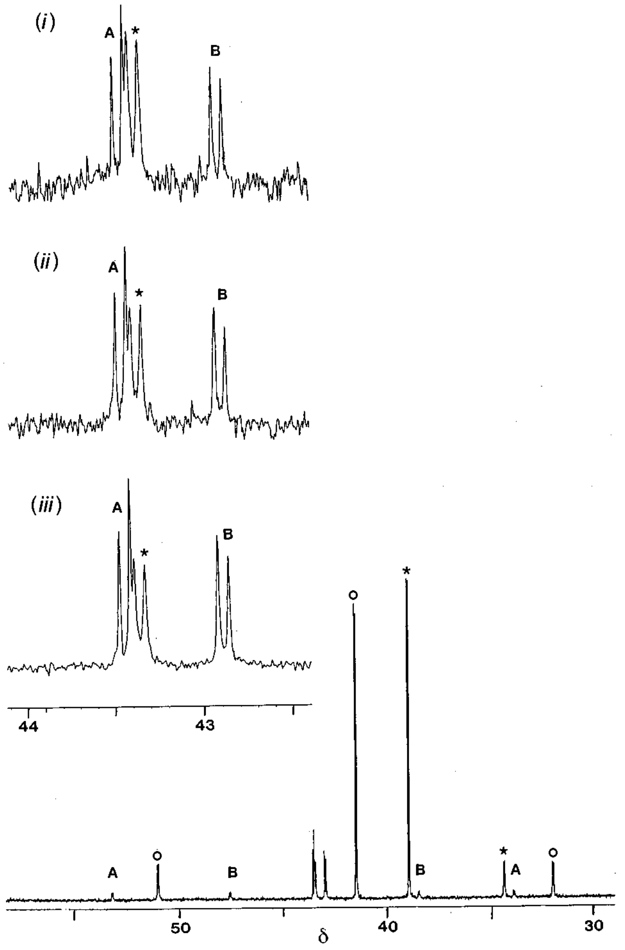
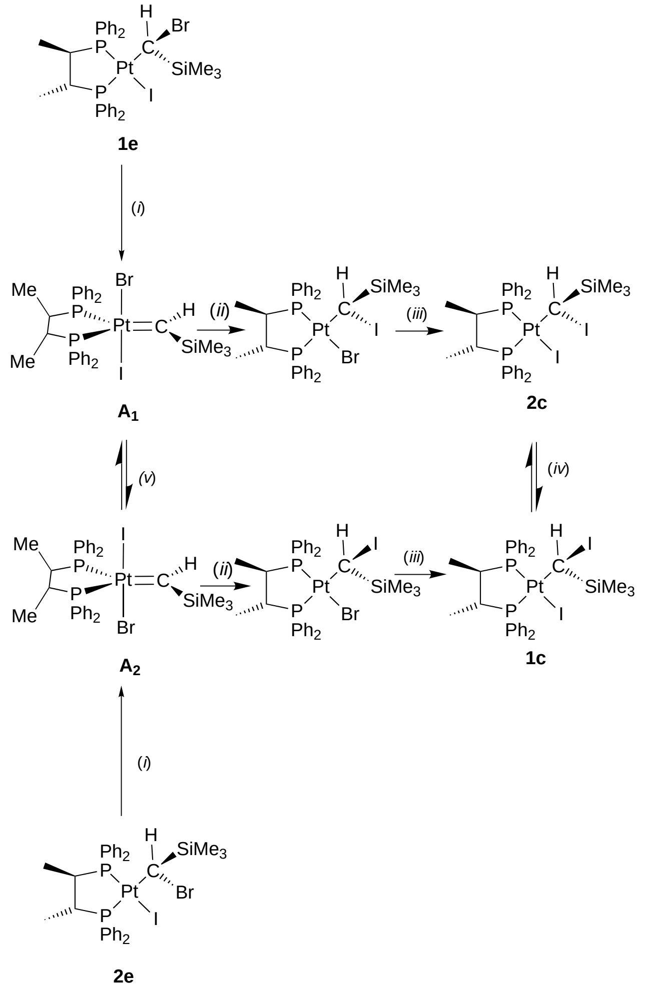


Fig. 4 The ^{31}P NMR spectra (202 MHz) obtained upon treatment of [PtBr(S-CHBrSiMe$_3$)(R,R-chiraphos)] **2b** with saturated NaI in CD$_3$CN. After 2 h the spectrum shown at the bottom was obtained where signals for the major product [PtI(R-CHISiMe$_3$)(R,R-chiraphos)] **1c** are identified by the symbols O (for the P *trans* to I) and * (for the P *trans* to CHISiMe$_3$). The expanded plots in the insets (*i*)–(*iii*) show the region where the central peaks for the minor product, [PtI(S-CHISiMe$_3$)(R,R-chiraphos)] **2c**, occur, identified by **A** (for the P *trans* to I) and **B** (for the P *trans* to CHISiMe$_3$); the peak marked * is the low-field ^{195}Pt satellite of the resonance for the P *trans* to CHISiMe$_3$ in the major isomer **1c**. The evolution of the spectra after (*i*) 6, (*ii*) 15 and (*iii*) 60 min shows the increase in intensity of the **A** and **B** resonances at the expense of the satellite peak *

Discussion

The main conclusions from the above results are: (*i*) the substitution of a halogen on carbon in the complexes **1d**, **2d** and **2e** by iodide are first-order reactions; (*ii*) the rate for **2d** is *ca.* 10^2 times faster than for **1d** and that for **2e** is *ca.* 40 times faster than for **1e**; (*iii*) substitution at the α-carbon in **2e** proceeds with predominant inversion of configuration.

Previously we have shown[2] that the complexes **1a**–**1c** epimerise to the less stable diastereoisomers **2a**–**2c** by a unimolecular process for which we proposed the participation of a platinum(II)–carbene complex. In Scheme 2 an analogous mechanism is proposed for the transformations **2e** $\longrightarrow$ **1c** and **2c** and for **1e** $\longrightarrow$ **1c** and **2c**. Steps labelled (*i*) are the formation of the five-co-ordinate platinum–carbene intermediates $\mathbf{A_1}$ and $\mathbf{A_2}$ by bromine migration from carbon to platinum. Migration of the iodine from platinum to carbon [steps (*ii*)] followed by rapid substitution of the bromine on platinum [step (*iii*)] would give **2c** from $\mathbf{A_1}$ and **1c** from $\mathbf{A_2}$ which then epimerise to give equilibrium mixtures of **1c** and **2c** [step (*iv*)]. The independence of the rate for **2e** on iodide concentration is explained if step (*i*) is the rate-determining step. The observed inversion of configuration in the reaction of **2e** would be expected if the rotation about the Pt=C bond [step (*v*)] is slow relative to the migration of iodide [step (*ii*)].



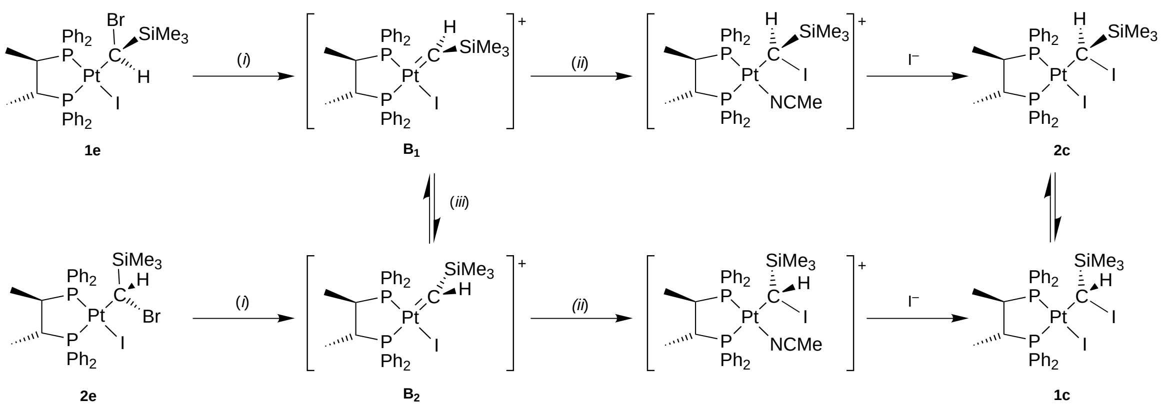
Scheme 2

The equilibrium constants[2] for **1b** $\rightleftharpoons$ **2b** and **1c** $\rightleftharpoons$ **2c** are both *ca.* 5 at 25 °C and therefore ground-state differences in stabilities between **1e** and **2e** would account for a difference in rate of a factor of *ca.* 5. The observation that the rates differ by a factor of 40 implies that **1e** and **2e** do not go through a common transition state and is consistent with the intermediates $\mathbf{A_1}$ and $\mathbf{A_2}$ not being in rapid equilibrium [*i.e.* step (*v*) in Scheme 2 is slow] and $\mathbf{A_1}$ being less stable than $\mathbf{A_2}$. A similar explanation can be given for the observations on the substitutions for the chloro complexes **1d** and **2d**.

The mechanism shown in Scheme 2 is attractive because it parallels that which we proposed, on the basis of strong evidence, for the epimerisations of **1a**–**1c**/**2a**–**2c**. However the ionic mechanism shown in Scheme 3 would also explain our observations. Dissociation of the halide [step (*i*)] would give the cationic carbene complexes $\mathbf{B_1}$ and $\mathbf{B_2}$ and then if migration of the co-ordinated iodide [step (*ii*)] occurred rapidly relative to Pt=C bond rotation [step (*iii*)] or indeed was synchronous with halide dissociation, then the observed first-order kinetics with inversion at the α-carbon can be rationalised. We[6] and others[4] have previously proposed cationic carbene complexes similar to **B** as intermediates in the reactions of α-halogenoalkylplatinum(II) complexes.

The reaction between Me_3SiCH_2Cl and KI in acetone was reported[7] to be second order with $\Delta G^{\ddagger}$ of the order of 100 kJ mol^{-1} at 20 °C. It has been established that carbonium ions are greatly destabilised by an α-$SiMe_3$ substituent and hence S_N1 mechanisms are generally disfavoured for $Me_3SiCHRCl$.[8] We have now shown that when R = PtI(*R*,*R*-chiraphos) the mechanism of the substitution is profoundly changed. It is not possible to compare directly the rate constants for R = H and PtI(*R*,*R*-chiraphos) because of the different orders of reaction and the reactions were carried out in different solvents (MeCN and Me_2CO); however $\Delta G^{\ddagger}$ for substitutions of **1d** was *ca.* 30 kJ mol^{-1} and for **2d** was *ca.* 20 kJ mol^{-1} indicating that the PtI(*R*,*R*-chiraphos) substituent dramatically reduces the activation energy for the substitution of the α-chlorine.

In conclusion we have presented kinetic evidence that substitution of the halogen atoms in the α-halogenoalkylplatinum complexes **1a**–**1c** and **2a**–**2c** by iodide is a first-order process which can be explained by a mechanism involving neighbouring-group participation (NGP) by platinum(II). Unlike conventional NGP where retention of configuration at



Scheme 3

tetrahedral carbon is the norm,[9] we have observed inversion upon substitution of halogen in **2e**. This opens up the possibility that, if epimerisation of the final product could be avoided [*e.g.* by using a carbon nucleophile such as CN^- or $CH(CO_2Et)_2^-$], then stereospecific substitution might be achieved.

Experimental

General methods were similar to those used in recent work from this laboratory.[2] All the experiments were carried out in air. The complexes $[PtX(CHXSiMe_3)(R,R\text{-chiraphos})]$, X = Cl, Br or I, were made as previously described.[3] The ^{31}P NMR spectra at 81 MHz were measured at +22 °C using a Bruker AM200 spectrometer and at 202 MHz at +22 °C using a JEOL Alpha 500 spectrometer. Chemical shifts (δ) are to high frequency of 85% H_3PO_4. Polarimetric measurements were performed on a Perkin-Elmer 241 instrument at 25 °C.

Iodide substitution

^{31}P NMR spectroscopy. In a typical experiment, the complex (18 mg) was dissolved in a solution of NaI in CD_3CN (0.6 cm^3, 0.1–0.5 M) and the spectra recorded at convenient intervals ranging from every 24 h (for **1a**) to every 2 min (for **2e**).

Polarimetry. In a typical experiment the complex (10 mg) was dissolved in a solution of NaI in MeCN (1 cm^3, 0.1–0.5 M) and the values of optical rotation recorded at convenient intervals ranging from every 5 min (for **2a**) to every 10 s (for **2e**).

Kinetic analysis

NMR measurements. We have previously shown that integration of the ^{31}P NMR signals is valid for determining the amounts of the reactants and products. The values of k_{obs} were obtained from the slope of a plot of $\ln(A/A_0)$ against time t. The plots are deposited as SUP 57301 and an example is shown in Fig. 1.

Polarimetry measurements. The values of k_{obs} were obtained from a fitting of an exponential function to a plot of rotation angle α against time t. All of the plots are deposited as SUP 57301 and examples are shown in Figs. 2 and 3.

Acknowledgements

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