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Carbohydrate phosphinites as chiral ligands for asymmetric synthesis catalyzed by complexes

V*. New rhodium(I)-chelates prepared by precipitation from the equilibrium between neutral and cationic complexes and hydrolysis of their bonded ligands

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Abstract

Some byproducts of the preparation of cationic rhodium(I)bis(phosphinite)-chelates **3** from rhodium(I)-[(*Z*,*Z*)-cycloocta-1,5-diene]-acetylacetonate, 4,6-*O*-alkylidene-glucopyranoside-2,3-*O*-bisphosphinite **1**, such as ligand and acid HA can be isolated. Neutral bis(phosphinite)complexes **2** having acetylacetonate as chelating anion and being inactive to hydrogenation, are separated from the equilibrium with cationic complexes **3** by precipitation using polar solvents. The acids, HA, as catalysts for solvolysis give the new cationic chelates **4** in a prolonged reaction. The chelates **4** exhibit excellent catalytic properties in asymmetric hydrogenation and possess free hydroxy groups in the 4,6 positions of the carbohydrate ligand.

Introduction

The formation of cationic rhodium(I) complexes from neutral rhodium(I)-acetylacetonato chelates under elimination of acetylacetone by reaction of acids with weakly coordinating anions has been studied by Johnson et al. [2]. Such cationic rhodium(I) complexes with trivalent phosphorus ligands have found wide application as catalysts [3] owing to their high activity allowing up to four free or low-occupied coordination sites for binding of substrates [4]. In our experiments on

* For part IV see ref. 1.

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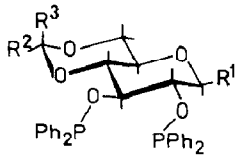
the preparation of the cationic complexes, **3a**, with carbohydrate-bis(phosphinites) of the Ph-β-glup type, such as **1a** [1], according to equation 1, where COD = (*Z*,*Z*)-



glup		R^1	R^2	R^3
Ph-β-glup	1a	OPh	Ph	H
	1b	OPh	Me	Me
	1c	Ph	Me	Me

$$[Rh(COD)acac] + \mathbf{1a} + S^1 \xrightarrow[2.+S^1]{1.+HA} \underset{(\mathbf{3a})}{[Rh(\mathbf{1a})(COD)]A} + Hacac \qquad (1)$$

cycloocta-1,5-diene; Hacac = acetylacetone; HA = acid; S^1 = solvent using HBF_4, H_2SO_4, $HClO_4$, HPF_6, H_3PO_4 or *p*-toluenesulfonic acid as the acid HA we obtained the pure chelates **3a** in high yields under the conditions as follows:

(a) For the chelate-forming reaction, a solvent, S^1, in which all complexes have good solubility, is preferred. In general, tetrahydrofuran (THF) is favoured [5], but methylenedichloride can also be used [6].

(b) The duration of action of the acids, HA, in the mixture should be short (10 minutes or less), so as to prevent the formation of an impure complex mixture as a consequence of incipient solvolysis of the complex-bound ligand giving chelates of type **4**.

(c) The solvent S^2 used for the precipitation of the chelates **3** should be nonpolar, e.g. diethyl ether, cyclohexane or n-pentane, otherwise impure neutral complexes **2**, which are almost inactive in hydrogenation, could result.

In this paper we describe the preparation of the pure chelate by-products. The new type of cationic chelates **4** with solvolysed carbohydrate ligand carrying free hydroxy groups is especially interesting owing to their increased activity and enantioselectivity relative to the chelates **3**. We present two new examples **3a** and **3b**, having isopropylidene as the protecting group in the 4,6 positions of the carbohydrate, and synthesized from $[Rh(COD)_2]BF_4$ and the new ligands **1b** and **1c**.

Results and discussion

The cationic rhodium(I)-(Ph-β-glup) complexes, **3a** resulting from the reaction of rhodium-(*Z*,*Z*)-cycloocta-1,5-diene-acetylacetonate with bisphosphinite **1a** under acidic conditions in solvent S^1 according to equation 1, can be separated out by addition of a nonpolar solvent S^2, such as diethyl ether (Et_2O). Use of alcohols or water for this purpose in some cases gave impure products in yields of up to 74%. After recrystallization the pure, neutral rhodium(I)-glup-acetylacetonato-complexes, **2a**, containing one mole solvent S^1 (THF) (as determined by GC) were obtained. This shows that the cationic complexes **3a** form an equilibrium (3) with the neutral complexes **2a**, originating from reaction 2.

$$\underset{\mathbf{1a-1c}}{[Rh(COD)acac] + glup} + S^1 \rightleftharpoons \underset{\mathbf{2a-2c}}{[Rh(glup)acac(S^1)]} + COD \qquad (2)$$

$$\mathbf{2a-2c} + HA + COD \rightleftharpoons \underset{\mathbf{3a-3c}}{[Rh(glup)(COD)]A} + Hacac + S^1 \qquad (3)$$

The neutral chelates **2** can be prepared readily and with greater purity if precipited from the reaction mixture of equation 2 without the acid HA but this was not our aim. Solvent S^1 can be readily exchanged with another similar solvent according to equation 4. In one case

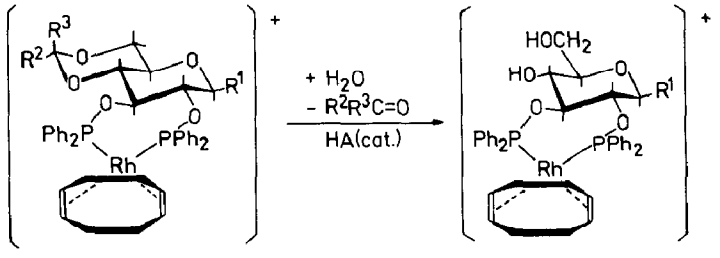
$$\underset{\mathbf{2a\alpha}}{[Rh(Ph\text{-}\beta\text{-glup})acac(THF)]} + Et_2O \rightleftharpoons \underset{\mathbf{2a\beta}}{[Rh(Ph\text{-}\beta\text{-glup})acac(Et_2O)]} \qquad (4)$$

a chelate $[\langle Rh(Ph\text{-}\beta\text{-glup})acac\rangle_2COD]$, **2a**$\gamma$ with half a cyclooctadiene instead of S^1 was isolated. One similar binuclear complex in which the bridging (*Z*,*Z*)-cycloocta-1,5-diene has a chair conformation is already known [13] (see also ref. 14).

The neutral complexes **2** are destroyed by oxygen more readily than the cationic complexes **3**. The strongly-bonded acetylacetonato ligand, readily discernable in the IR-spectra (ν(C=O) 1520, 1580 cm^{-1}) gives rise to the catalytic inactivity of the pure chelates **2** in our standard hydrogenation reaction [4]. The half-life of the hydrogenation of the acetamidocinnamic acid ester exceeds 30 hours! It is noteworthy that the delivery of **2** from cationic complexes **3**, according to equilibrium 3, requires both the replacement of A^- by $acac^-$ and the exchange of the chelating COD by S^1. This may be the reason why in the precipitation with polar protic solvents, impure products have been observed in most cases.

In contrast the cationic species **3** can be precipitated in high yield and relatively high purity by nonpolar solvent S^2 within 10 minutes, any longer and the chelated glup ligand begins to undergo solvolysis in prolonged reaction brought on by traces of a protic solvent under the catalytic influence of the acid HA according to equation 5. Traces of water originating from the acid used, such as 75% HPF_6, have been sufficient to hydrolyze **3a** to **4a** to an extent of about 50% within 20 hours. It is possible to separate the complex pairs **3a**/**4a** carrying the four A^- anions: PF_6^-, HSO_4^-, BF_4^- and ClO_4^- by TLC under anaerobic conditions.

Initially we were unable to obtain pure **4a**-type complexes from the Ph-β-glup chelates **3a**. In addition the phenyl glucopyranoside as the acetal, and the two O–P bonds are sensitive to solvolysis so we had to avoid rigorous conditions such as higher temperatures. Thus we prepared the new, analogous 4,6-*O*-isopropylidene chelate **3b** which is more unstable to solvolysis by one order of magnitude owing to



(5)

	R^1	R^2	R^3			
3a	OPh	Ph	H	→	4a=4b	R^1 = OPh
3b	OPh	Me	Me	↗		
3c	Ph	Me	Me	→	4c	R^1 = Ph

steric and electronic effects viz. the axial methyl group and the $+I$-effect of both methyl groups, respectively [7,8].

The hydrolysis of the isopropylidene protecting group can be followed to completion of the reaction by GLC analysis of the acetone formed from the head space. The reaction goes to completion within 5 hours if 40% HBF_4 is used. The [**4b**]BF_4 formed can be precipitated by diethyl ether in 81% yield and is analytically pure. The susceptibility of the chelate to further solvolysis is not high. If the reaction is prolonged to 50 hours the complex remains nearly unchanged and no phenol can be detected with the sensitive colorimetric method of Martin [9]. The analogous *C*-glucoside chelate [**4c**]BF_4 without the acetal group is synthesized similarly.

In the knowledge that [**4b**]BF_4 is highly stable we have successfully prepared [**4a**]A complexes in substance and in situ starting from the more accessible Ph-β-glup, **1a**. A good indication of a successful hydrolysis can be gained from the determination of the enantioselectivity, in the hydrogenation of methyl acetamidocinnamate in methanol, which increases from 91.5 to 95.0 ± 1% ee methyl (*S*)-*N*-acetylphenylalaninate and is characteristic of all hydroxy groups carrying carbohydratebisphosphinite chelates of the formula [**4**]A independent of the anion A^-. The determination of hydroxy groups by IR is not satisfactory because the solid preparations often contain varying amounts of additionally bound acid and/or water.

Rhodium chelates [**3b**]BF_4 and [**3c**]BF_4 carrying the new glup-type ligands **1b** or **1c**, which are especially acid-labile even in complexed form, are prepared from $[Rh(COD)_2]BF_4$ and ligand according to equation 6 to avoid influences by acid.

$$[RH(COD)_2]BF_4 + \mathbf{1b,1c} \rightarrow [Rh(\mathbf{1b,1c})(COD)]BF_4 + COD \qquad (6)$$

The properties of all the chelates obtained from the asymmetric hydrogenations will be described in part VI of this series.

Experimental

Melting points were determined on a Boëtius melting point apparatus and are corrected. Infrared spectra were recorded on a Beckman IR12 spectrometer or a Specord M80 of VEB Carl Zeiss, Jena. Standard hydrogenation experiments with 1 mmole methyl (*Z*)-acetaminocinnamate and 0.01 mmole catalyst in 15 ml methanol (0.1 MPa H_2, 25 °C, were conducted as described previously [4], with GLC determinations of the enantiomeric excess of methyl *N*-acetylphenylalaninate. A Hewlett Packard 5800A chromatograph was used. For a GLC study of the coordinated solvents and COD, respectively, 1 μmole complex was dissolved in 200 μl of a solution containing 10 μmole 1,2-bis(diphenylphosphino)ethane and 0.73 μmole n-decane (internal standard) in freshly distilled 1,1,2,2-tetrachloroethane. All complexes dissolved very quickly and were analyzed on a 50 m OV1 capillary column with a temperature programme as follows: 6 min at 35 °C, 10 °/min up to 150 °C, 30 min at 150 °C. Comparison with standard solutions gave a standard deviation of $s \leqslant 0.1$ mmole S^1 (COD)/mmole Rh.

Materials. All manipulations were carried out, and all solvents were kept, under anaerobic and anhydrous conditions. Ph-β-glup **1a** was prepared as previously described [4], as were the other bisphosphinites **1b,1c**. The syntheses of their precursors, and their NMR data, will be described elsewhere [10].

For the preparation of [Rh(COD)acac] in high yield (97 ± 2%) the method of Cramer [11] was modified [12]. For purification, 20 g of the complex were dissolved in 30 ml CH_2Cl_2 (30 ml) and after filtration methanol (120 ml) at 40 °C was added yielding 17,7 g pure product on cooling. The residual mother liquor can be added to the next purification.

1. [Rh(Ph-β-glup)acac(THF)] (2aα)

To the yellow solution obtained by dissolving 0.775 g (2.5 mmole) of [Rh(COD)acac] and 1.79 g (2.5 mmole) of Ph-β-glup **1a** in 2.5 ml of THF is added 0.17 ml of H_3PO_4 (85%) *. After one hour, addition of 7 ml methanol leads to an intermediate sticky mass which soon dissolves. After fifteen minutes, yellow crystals begin to separate and a further 5 ml methanol is added. The mixture is then stirred for one hour. After cooling overnight, filtration, washing three times with 3 ml of methanol, and drying, 1.66 g of crude **2aα** (67%) are obtained; m.p. 147–155 °C. Found: C, 63.31; H, 5.56; P, 6.70; Rh, 10.49. $C_{52}H_{53}O_9P_2Rh$ calc.: C, 63.29; H, 5.41; P, 6.28; Rh, 10.43%. There is 0.9 mole of THF, found by GLC, COD is missing. IR(KBr), ν(C=O) 1520 and 1580 cm^{-1}.

2. [Rh(Ph-β-glup)acac(Et_2O)] (2aβ)

By repeated extraction of 0.8 g (0.81 mmole) of [Rh(Ph-β-glup)acac(THF)], **2aα**, with 20 ml of boiling Et_2O from a glass filter disc, the ether molecules exchange and after cooling, pure **2aβ** forms as light-yellow crystals; 0.48 g (60%); m.p. 154–157 °C. Found: C, 63.02; H, 5.33; P, 6.35; Rh, 10.38. $C_{52}H_{55}O_9P_2Rh$ calc: C, 63.15; H, 5.61; P, 6.27; Rh, 10.41%. There is 0.9 mole Et_2O found by GLC, COD is missing. IR(KBr), ν(C=O) 1520 and 1580 cm^{-1}.

3. [Rh(Ph-β-glup)acac]$_2$(COD) (2aγ)

To the solution of 0.775 g (2.5 mmole) of [Rh(COD)acac] and 1.79 g (2.5 mmole) of Ph-β-glup **1a** in 2.5 ml of THF is added 0.18 ml of conc. H_2SO_4 **. After one hour 7 ml of methanol and then 20 ml of airfree water are added to give a yellow crystalline product, which is washed three times with a mixture of methanol/water (2:1) to give **2aγ**, contaminated by about 10% [Rh(Ph-β-glup)COD]HSO_4 as deduced from the small content of sulfur (0.27%) and containing 0.6 mmole COD (GLC). Activity in standard hydrogenation reactions was evident [4] (half-life; 67 min) Yield 1.79 g (74%); m.p. 105–117 °C. Found: C, 63.90; H, 5.70; P, 5.93; Rh, 10.63; S, 0.27. $C_{104}H_{102}O_{16}P_4Rh_2$ calc: C, 64.46; H, 5.31; P, 6.39; Rh, 10.62; S, 0.00%. IR(KBr), ν(C=O) 1520 and 1580 cm^{-1}.

4. [Rh(1b)COD]BF_4 (3b)

[Rh(COD)$_2$]BF_4 (0.406 g (1 mmole)) and 0.731 g (1.1 mmole) of the newly synthesized phenyl 4,6-*O*-isopropylidene-2,3-*O*-bis(diphenylphosphino)-β-D-gluco-pyranoside **1b** [10], in 80 ml of boiling THF are dissolved with stirring. After 20 minutes the solution is concentrated to 15 ml, and 50 ml of Et_2O are added. Under stirring the orange-red complex separates. Filtration on the day after, washing 3

* Without H_3PO_4 a purer **2aα** is obtained

** Without H_2SO_4 an analytically pure **2aγ** is obtained, m.p. 117–123 °C.

times with 3 ml Et_2O and drying gives 0.62 g (64.3%) of analytically pure **3b**, a second, less pure fraction of 0.14 g (14.4%) can be obtained from the mother liquor. Found: C, 58.29; H, 5.54; P, 6.00; Rh, 10.97. $C_{47}H_{50}BF_4O_6P_2Rh$ calc: C, 58.64; H, 5.24; P, 6.44; Rh, 10.69%.

5. [Rh(1c)COD]BF_4 (3c)

The complex **3c** having the new phenyl-*C*-glucopyranoside ligand 4,6-*O*-isopropylidene-2,3-*O*-bis(diphenylphosphino)-β-D-glucopyranosylbenzene **1c** [10] is obtained in the same manner as the analogous *O*-glucoside chelate **3b**. The separation of the complex into the crystalline form is slow and requires lengthy stirring. It is more useful to seed the mixture with crystals from part of the oily complex under cyclohexane. We isolated analytically pure **3c** in 78.7% yield. Found: C, 59,63; H, 5.58; P, 6.65; Rh, 10.72. $C_{47}H_{50}BF_4O_5P_2Rh$ calc: C, 59,64; H, 5.32; P, 6.54; Rh, 10,87%.

6. [Rhodium{phenyl 2,3-O-bis(diphenylphosphino)-β-D-glucopyranoside}(COD)]PF_6 ([4a]PF_6), impure

A solution of 0.465 g (1.5 mmole) of [Rh(COD)acac] and 1.074 g (1.5 mmole) of Ph-β-glup in 1.5 ml of THF to which was added 0.25 ml of 75% HPF_6 (2.15 mmole) gave a small number of crystals within 90 minutes but the yield scarcely increased in the refrigerator during 20 hours. Addition of 6 ml of Et_2O gives a sticky orange-red mass. It becomes crystalline after 15 minutes stirring and can then be filtered. The Et_2O washings smell of benzaldehyde. In anaerobic TLC on Silufol UV_{254} (Sklárny Kavalier, Czechoslovakia) with acetone/benzene (1 : 1) as eluent the impure product [**4a**]PF_6 (1.1 g, 65%) shows two spots of similar extent (R_f 0.46 and 0.66), the latter being that of authentic [**3a**]PF_6 [1]. The mixture shows an enantioselectivity of 94.4 + 0.5% ee methyl (*S*)-*N*-acetylphenylalaninate in a standard hdyrogenation compared with 91.7 ± 0.5% ee for the pure [**3a**]PF_6 [1].

The elemental analysis points to an almost equimolar mixture of both complexes carrying some water, but, we cannot explain why there is such a sharp melting point (171–172.5 °C) for the rather well-developed crystals. The results of Chizhevsky et al. [15] indicate that hydrolysis of the PF_6^- to $F_2P(O)O^-$ may also play a role in our case. The latter ion is able to form bridges between two hydroxyl group-carrying rhodium-chelate species [15].

Found: C, 54.15; H, 5.03; P, 8.30; Rh, 9.85. calc: C, 53.78; H, 4.94; P, 8.76; Rh, 9.70% for [**4a**]PF_6 · [**3a**]PF_6 · $4H_2O$: $C_{95}H_{104}F_{12}O_{16}P_6Rh_2$. There are 0.9 ± 0.1 mmole COD/Rh (by GLC). An IR spectrum in Nujol shows unusually sharp OH absorptions at 3550 and 3610 cm^{-1} falling to 2625 and 2675 cm^{-1} upon deuteration.

7. [Rhodium{phenyl 2,3-O-bis(diphenylphosphino)-β-D-glucopyranoside}(COD)]BF_4 ([4b]BF_4)

To the yellow solution of [Rh(**1b**)acac(THF)] (**2b**) formed from 310 mg (1.0 mmole) of [Rh(COD)acac] and 665 mg (1.0 mmole) of phenyl 4,6-*O*-isopropylidene-β-D-glucopyranoside (**1b**) in 5 ml of THF is added, 0.52 ml (3 mmole) 40% aqueous HBF_4. The colour changes to orange-red indicating the formation of the cationic complex [**3b**]BF_4. From time to time, 200 μl from the vapour of the head space is taken for GLC detection of acetone and compared with standard acetone/THF mixtures, so that the end point of the hydrolysis can be estimated (achieved after 5

hours). The precipitation of [**4b**]BF_4 is initiated by addition of 20 ml of Et_2O. At first a suspension of a fine orange material is formed, but this becomes a grease and only after prolonged stirring does it become crystalline. The material is filtered, washed 3 times with 5 ml of Et_2O and dried, to give 0.75 g [**4b**]BF_4 (81%). Found: C, 57.11; H, 4.95; P, 7.10; Rh, 11.37. $C_{44}H_{46}BF_4O_6P_2Rh$ calc: C, 57.28; H, 5.03; P, 6.72; Rh, 11.15%. IR (Nujol), ν(OH) 3488, 3560 cm^{-1}. IR (3×10^{-3} m in CH_2Cl_2), ν(OH) 3496, 3596 cm^{-1}.

*8. [Rhodium{2,3-O-bis(diphenylphosphino)-β-D-glucopyranosylbenzene}(COD)]BF_4 ([**4c**]BF_4)*

The reaction of 0.93 g (3 mmole) of [Rh(COD)acac] and 1.95 g (3 mmole) of 4,6-*O*-isopropylidene-β-D-glucopyranosylbenzene (**1c**) in 17.5 ml of THF immediately gives the yellow solution of [Rh(**1c**)acac(THF)] (**2c**). Addition of 1.54 ml (9 mmole) of 40% aqueous HBF_4 causes a colour change to orange-red indicating the formation of [**3c**]BF_4. Within 5.5 hours the hydrolysis to [**4c**]BF_4 is complete (GLC of acetone). Addition of 30 ml of Et_2O may lead to some precipitation within one hour. Dropwise addition of a further 30 ml Et_2O and stirring for a longer period yields more crystals. After cooling in the refrigerator, filtration, and washing 3 times with Et_2O 1.71 g (63%), analytically pure [**4c**]BF_4 is obtained. Found: C, 58.35; H, 5.29; P, 7.05; Rh, 11.01. calc: $C_{44}H_{46}BF_4O_5P_2Rh$: C, 58.30; H, 5.12; P, 6.83; Rh, 11.35%. IR (Nujol), ν(OH) 3500–3552, 3582 cm^{-1}. IR (3×10^{-3} m in CH_2Cl_2), ν(OH) 3596 cm^{-1} (shoulder 3525 cm^{-1}).

*9. [Rhodium{phenyl 2,3-O-bis(diphenylphosphino)-β-D-glucopyranoside}(COD)]HSO_4 ([**4a**]HSO_4)*

To the yellow solution of 1.55 g (5 mmole) of [Rh(COD)acac] and 3.58 g (5 mmole) of Ph-β-glup, **1a**, in 5 ml of THF is added 0.5 ml (5.7 mmole) of 70% aqueous H_2SO_4, and the solution turns red. After four days standing at room temperature and two days in the refrigerator the mixture becomes solid. It can be filtrated in the air by suction. After washing twice with 3 ml of THF, twice with 5 ml of a mixture of THF/Et_2O (1 : 1) and finally with 7 ml of Et_2O, 3.3 g (70.8%) of orange [**4a**]HSO_4 is obtained. Found: C, 56.48; H, 5.14; P, 6.38; Rh, 10.79; S, 3.76. $C_{44}H_{47}O_{10}P_2RhS$ calc: C, 56.65; H, 5.08; P, 6.64; Rh, 11.03; S, 3.44%. IR (Nujol), ν(OH) 3320 cm^{-1} (broad).

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References

1 R. Selke, J. Prakt. Chem. 329 (1987) 717.
2 B.F.G. Johnson, J. Lewis and D.A. White, J. Am. Chem. Soc. 91 (1969) 5186.
3 R.R. Schrock and J.A. Osborn, J. Am. Chem. Soc. 98 (1976) 2134.
4 R. Selke and H. Pracejus, J. Mol. Catal. 37 (1986) 213.

5 R.R. Schrock and J.A. Osborn, J. Am. Chem. Soc. 93 (1971) 2397.
6 J. Reiss and J. Hetflejš, Collect. Czech. Chem. Commun. 51 (1986) 340.
7 A.N. De Belder, Advances in Carbohydrate Chemistry, Academic Press, New York 1965, Vol. 20, p. 219, 235.
8 A.N. De Belder, Advances in Carbohydrate Chemistry and Biochemistry, Academic Press, New York 1977, Vol. 34, p. 179, 202.
9 M.E. Martin, Anal. Chem. 21 (1949) 1419.
10 R. Selke et al., submitted to Carbohydr. Res.
11 R. Cramer, J. Am. Chem. Soc. 86 (1964) 217.
12 R. Selke, E. Paetzold, H. Grüner, DD 243 189 A3, 25. 02. 87.
13 C. Krüger, J. Organomet. Chem. 22 (1970) 697.
14 W. Griffith, S.A.R. Knox, R.F.D. Stansfield, F.G.A. Stone, M.J. Winter, P. Woodward, J. Chem. Soc., Dalton Trans. (1982) 159.
15 I.T. Chizhevsky, N.V. Rastova, N.E. Kolobova, P.V. Petrovskii, E.I. Fedin, L.E. Vinogradova, L.A. Leites, A.I. Yanovsky and Yu.T. Struchkov, J. Organomet. Chem. 339 (1988) 165.