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# Reaction of Mo(CO)<sub>4</sub>(NCCH<sub>3</sub>)<sub>2</sub> and 7-aza-2-Tosylnorbornadiene

Note

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#### Abstract

Reaction of Mo(CO)<sub>4</sub>(NCCH<sub>3</sub>)<sub>2</sub> and 7-aza-2-tosylnorbornadiene (7-azaNBD) yielded five air-stable Mo complexes. One is Mo(CO)<sub>4</sub>( $\eta^4$ -7-azaNBD), in which the molybdenum atom is chelated by the two  $\pi$ -bonds of 7-azaNBD. The other four are isomers of Mo(CO)<sub>2</sub>( $\eta^2$ -7-azaNBD)<sub>2</sub>, in which the molybdenum atoms are chelated by the nitrogen atom and one of the two double bonds of 7-azaNBD. In one pair of the isomers, the metal binds to C(2)=C(3) of both 7-azaNBD ligands; whereas in the other pair of isomers the metal binds to C(2)=C(3) of one 7-azaNBD ligand and C(5)=C(6) of another ligand. All structures were fully characterized by NMR spectra. A single crystal of compound **4** was analyzed by X-ray diffraction analysis, which was found to be monoclinic with *a* = 8.4199, *b* = 23.984, *c* = 16.395 Å, and  $\beta$  = 99.99°. © 2005 Elsevier B.V. All rights reserved.

#### 1. Introduction

Norbornadiene (NBD) has been widely applied as a ligand for the preparation of organo-metal complexes. Number of studies revealed that the molybdenum may form stable complexes with either one NBD unit (i.e.,  $Mo(CO)_4(NBD)$ ) or with two NBD units (i.e., Mo  $(CO)_2(NBD)_2$  [1]. The coordination of NBD to the Mo in  $Mo(CO)_4(NBD)$  is comparably labile, therefore it can be replaced for synthetic purpose by a wide range of other ligands, such as phosphines, amines, arsines, isonitriles, 1,5-COD, etc. [1h,11]. This methodology has been utilized successfully for the preparation of various organometallic compounds and catalysts. The derivatives of NBD containing a heteroatom (O, N) at 7-position have also been studied on similar purpose. Irradiation of either 7-oxabenzonorbornadiene (7-oxaNBD), 5,6-dimethylene-7-oxanorborene, or 2,3-dicarbomethoxy-7-oxa- norbornadiene under UV light in the presence of Fe(CO)<sub>5</sub> or  $Fe_2(CO)_9$  yielded the stable iron carbonyl complexes. In

these structures, the iron metal was coordinated to the  $\pi$ -bond on the *exo* side [2]. However, the oxygen atom with lone pairs in these complexes does not show strong bonding toward the metal, even though they were located in close proximity. Heating these complexes until fragmentation did not yield any intermolecular  $[2_{\pi} + 2_{\pi}]$  cyclic adduct. The analogous complexes of nitrogen derivatives, i.e., 7-azanorbornadiene derivatives, showed different characteristics such as the appearance of strong bonding nature between the nitrogen atom and the metal [3]. Those 7-azanorbornadiene complexes underwent nitrene extrusion reaction upon heating to give  $(\eta^4$ -cyclohexadiene)iron carbonyl complexes [3a,3c,3e,3f]. To the best of our knowledge, the reaction of molybdenum metal with 7-azaNBD has not yet been reported, so it would be of general interests to describe the reaction of 2-tosyl-7-azanorbornadiene and Mo(CO)<sub>4</sub>(NCMe)<sub>2</sub>.

#### 2. Results and discussion

 $Mo(CO)_4(NCMe)_2$  was prepared from the reaction of  $Mo(CO)_6$  and  $Me_3NO$  in  $CH_3CN$  solution and the

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reaction is depicted as Scheme 1. The purified sample was then heated with an equal molar amount of 7-methoxycarbonyl-2-p-toluenesulfonyl-7-azanorbornadiene (7-azaNBD) in CH<sub>2</sub>Cl<sub>2</sub> for 40 h. The products were purified by column chromatography and five air-stable molybdenum complexes were isolated. The structures of 3-6 were determined by two-dimensional <sup>1</sup>H COSY and <sup>1</sup>H-<sup>13</sup>C COSY spectra, along with X-ray diffraction analysis on a single crystal of 4. The isotopic distribution pattern of Mo on mass spectrum is consistent with the natural abundance of Mo. Their physical data including <sup>1</sup>H and <sup>13</sup>C NMR chemical shift values are listed in Tables 1-3. Selected parameters of X-ray analysis of 4 are listed in Tables 4 and 5. The chemical shift values of 7-azaNBD are included for comparison purpose.

The  $v_{co}$  of **2** spread into three regions, i.e., 2071(m), 2008(vs); 1994(s, sh), 1944(s); and 1716(s) cm<sup>-1</sup>. The patterns of relative intensities corresponded to a *cis*-ML<sub>2</sub>(CO)<sub>4</sub> structure [4]. The first two sets are attributed by four COs and the last one is attributed by carbonyl of ester. The stretch of CO above 2000 cm<sup>-1</sup> is absent from the spectra of **3–6**. In correction of the structures between **2** and **3–6**, we can conclude that the signals of 2071 and 2008 cm<sup>-1</sup> of **2** are due to the stretch of CO

Table 1 The physical properties and spectral data of compounds  $1-6^a$ 



Scheme 1.

The physical properties and spectral data of compoundus 1–0									
Compounds	Mp °C (color)	Yield %	FABMS $[M + 1]^+$	IR cm <sup>-1</sup>					
1	91.5-92.3 (white)	61.0	305	1727 <sup>b</sup>					
2	128-129.5 (yellow)	12.6	516	2071(m) <sup>c</sup> , 2008(vs) <sup>c</sup> , 1994(s,sh) <sup>d</sup> , 1944(s) <sup>d</sup> , 1716(s) <sup>b</sup>					
3	137 (yellow)	10.2	765	$1984(s)^{d}, 1910(s)^{d}, 1756(s)^{b}$					
4	118-119.5 (yellow)	40.0	765	$1968(s)^d$ , $1890(s)^d$ , $1755(s)^b$					
5	126-127.5 (yellow)	23.7	765	$1968(s)^d$ , $1891(s)^d$ , $1755(s)^b$					
6	134-136 (yellow)	4.3	765	$1996(s)^d$ , $1919(s)^d$ , $1755(s)^b$					

<sup>a</sup> The errors for elemental analyses of C, H, N are within 0.2%.

<sup>b</sup> CO of ester.

<sup>c</sup> CO trans each other.

<sup>d</sup> CO trans to double bond.

Table 2					
<sup>1</sup> H NMR	spectral	data	of com	pounds	1–6

Compounds	H1	H3	H4	Н5	H6	$OCH_3$	CH <sub>3</sub>	Ar
1	5.44(s)	7.62(m)	5.22(s)	6.92(m)	6.96(m)	3.5(bs)	2.45(s)	7.33 (d, $J = 8.0$ Hz), 7.75 (d, $J = 8.0$ Hz)
2	5.36(bs)	4.91(m)	5.21(bs)	4.55(m)	4.86(m)	3.31(s)	2.41(s)	7.30 (d, $J = 8.0$ Hz), 7.74 (d, $J = 8.0$ Hz)
3	5.46(bs)	4.17(bs)	5.42(bs)	6.07 (dd,	5.72 (dd,	3.84(s)	2.44(s)	7.29 (d, $J = 8.0$ Hz), 7.67 (d, $J = 8.0$ Hz)
4	5.33(bs)	3.96(s)	5.22(bs)	J = 5.7, 1.9 Hz) 6.01 (dm, J = 5.0 Hz)	J = 5.7, 1.4 Hz) 5.70 (dm, J = 5.0 Hz)	3.73(s)	2.41(s)	7.25 (d, <i>J</i> = 8.1 Hz), 7.62 (d, <i>J</i> = 8.1 Hz)
	5.33(bs)	7.07(bs)	5.52(bs)	4.28 (d, $J = 5.0$ Hz)	3.87 (d, J = 5.0 Hz)	3.79(s)	2.45(s)	7.36 (d, $J = 8.1$ Hz), 7.74 (d, $J = 8.1$ Hz)
5	5.37(bs)	3.96(s)	5.22(bs)	5.99 (dm, J = 5.0 Hz)	5.69 (dm, J = 5.0 Hz)	3.73(s)	2.41(s)	7.25 (d, <i>J</i> = 8.2 Hz), 7.62 (d, <i>J</i> = 8.2 Hz)
	5.35(bs)	7.24(bs)	5.37(bs)	4.38 (d, J = 5.0 Hz)	3.91 (d, J = 5.0 Hz)	3.46(s)	2.47(s)	7.40 (d, $J = 8.2$ Hz), 7.81 (d, $J = 8.2$ Hz)
6	5.24(bs)	4.18(bs)	5.33(bs)	6.30(m)	6.03(m)	3.75(s)	2.43(s)	7.28 (d, $J = 8.2$ Hz), 7.67 (d, $J = 8.2$ Hz)
	5.48(bs)	4.07(bs)	5.37(bs)	6.03(m)	5.71(m)	3.84(s)	2.43(s)	7.32 (d, $J = 8.2$ Hz), 7.80 (d, $J = 8.2$ Hz)

Table 3 <sup>13</sup> C NMR spectral data of compounds **1–6** 

Compounds	C1	C2	C3	C4	C5	C6	$OCH_3$	$\mathrm{CH}_3$	Ar	СО
1	67.62	154.78	151.66	66.36	141.69	144.84	52.72	21.49	127.85,129.87,135.28,143.25	158.82(C=O)
2	65.24	85.86	70.32	65.09	85.86	72.68	52.74	21.58	128.01,129.86,137.29,144.33	150.74(C=O), 211.47, 213.35,
										215.06, 217.49
3	73.74	84.7	62.29	80.69	137.73	140.49	55.11	21.62	128.45,129.59,137.40,143.93	158.83(C=O), 228.07
4	73.62	83.06	60.63	81.34	136.82	140.98	55.09	21.69	128.14,130.00,138.02,145.14	156.84(C=O), 231.58
	73.01	156.41	144.52	79.48	63.75	58.61	54.61	21.54	127.80,129.47,136.32,143.60	156.11(C=O), 229.35
5	73.00	83.07	60.65	81.37	136.55	141.07	54.74	21.56	128.16,130.02,137.84,145.06	156.40(C=O), 229.26
	77.62	153.34	147.73	75.03	64.34	57.71	54.64	21.49	127.99,129.43,136.27,143.58	156.89(C=O), 231.40
6	78.45	83.7	59.82	76.32	140.02	138.42	54.88	21.62	128.43,129.61,137.43,143.93	156.84(C=O), 226.81
	73.49	88.55	61.34	82.07	136.88	141.72	55.17	21.62	128.54,129.69,137.73,144.16	156.84(C=O), 229.23

Table 4

Experimental	crystallographic	data collections	for compound <b>4</b>
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Formula	C33H32Cl2 MoN2O10S2
Formula weight	847.59
Diffractometer	Nonius
Space group	monoclinic $P2_1/n$
Unit cell dimensions	
$a(\text{\AA})$	14.481(4)
$b(\text{\AA})$	12.0152(18)
$c(\text{\AA})$	21.003(3)
β (°)	92.189(17)
Volume (Å <sup>3</sup> )	3651.7(12)
Ζ	4
$D_{\text{calc}} (\text{g/cm}^3)$	1.542
$\lambda$ (Å)	0.70930
$F(0\ 0\ 0)$	1728
Unit cell detn.: #; ( $2\theta$ range)	25; (14.91-33.71)
Scan type	θ/2 θ
h, k, l ranges	(-17; 17) (0; 14) (0; 24)
$\mu (\mathrm{cm}^{-1})$	6.623
Crystal size (mm)	0.28  imes 0.31  imes 0.38
Maximum and minimum	1.000; 0.960
reflection transmission	
Temperature (K)	298.0
Number of measured reflections	6689
Number of observed reflections $(I > 2.0\sigma(I))$	3818
Number of unique reflections	6418
RF; Rw	0.045; 0.050
Goodness of fit of F	1.70
Refinement program	NRCVAX
Number of atoms	82
Number of refined parameters	451 (3818 out of
	6418 reflections)
Minimize function	$\sum (w F_{\rm o} - F_{\rm c} ^2)$
Weights scheme	$\overline{(1/\sigma^2)}(F_{\rm o})$
$(\Delta/\sigma)$ max	0.0037
$\overline{R = \sum \ F_0\  -  F_0\  / \sum  F_0 }.$	
$R_{W} = \left[\sum_{w} ( F  -  F )^{2} / \sum_{w}  F ^{2}\right]^{1/2}$	

 $G_{\rm o}F = \sqrt{\left[\sum (w(F_{\rm o} - F_{\rm c})^2 / (\text{number of reflections} - \text{number of parameters}))\right]}$ 

with another CO at its trans position. The common two signals for CO appeared at the wavelengths below  $2000 \text{ cm}^{-1}$  with almost equal intensities, suggesting that the two CO groups are in *cis* relation. The stretches appearing at lower wavelengths are rationalized by the olefin group at its *trans* position. The chemical shifts of olefinic hydrogen in <sup>1</sup>H NMR spectrum and those

Table 5

Selected	bond	lengths	$(\mathbf{A})$	and	bond	angles	(deg)	in	compound 4 <sup>a</sup>	
			· /							

Bond lengths			
C11-C12	1.429(8)	C31–C32	1.397(8)
C14-C15	1.303(11)	C34–C35	1.329(9)
Mo-C1	1.964(7)	Mo-C2	1.959(7)
Mo-C11	2.182(2)	Mo-C34	2.250(6)
Mo-C12	2.213(6)	Mo-C35	2.200(6)
Mo-N1	2.376(5)	Mo-N2	2.335(4)
C1O1	1.140(8)	C2–O2	1.154(8)
Bond angles			
C1-Mo-C2	86.5(3)	C1-Mo-C11	111.75(24)
C1-Mo-C12	73.93(25)	C1-Mo-C34	90.92(24)
C1-Mo-C35	93.95(23)	C1-Mo-N1	95.66(21)
C1-Mo-N2	150.44(22)	C2-Mo-C11	99.23(24)
C2-Mo-C12	100.06(24)	C2-Mo-C34	74.42(24)
C2-Mo-C35	110.98(24)	C2-Mo-N1	156.18(22)
C2-Mo-N2	92.36(21)	C11-Mo-C12	37.93(22)
C11-Mo-C34	154.33(21)	C11-Mo-C35	141.45(21)
C12-Mo-C34	166.20(22)	C12-Mo-C35	146.00(21)
C34-Mo-C35	36.57(22)	N1-Mo-N2	97.08(16)
N1-Mo-C11	58.29(18)	N1-Mo-C12	58.29(19)
N1-Mo-C34	128.95(19)	N1-Mo-C35	92.57(19)
N2-Mo-C11	97.61(20)	N2-Mo-C12	15.02(21)
N2-Mo-C34	58.57(20)	N2-Mo-C35	36.57(22)

 $^{\rm a}$  C11, C12, C34, and C35 are corresponding to C2, C3, C5, and C6 in this text.

of the corresponding resonance of carbons in  ${}^{13}C$  NMR spectrum of ( $\eta^4$ -7-azaNBD)Mo(CO)<sub>4</sub> showed substantial upfield shifts (2.0–2.5 ppm for  ${}^{1}H$  and 70–80 ppm for  ${}^{13}C$ ). The strong bonding nature of Mo– $\pi$  coordination induced a change of hybridization on the carbon atoms from sp<sup>2</sup> to sp<sup>3</sup>.

This is confirmed by the substantial bond length change observed in compound **4** as described in the following section. The Mo atom is chelated by the double bonds of NBD on the *endo* side. This product is quite similar to that obtained in the reaction of iron carbonyl with NBD.

The molecular weights of compounds **3–6** were confirmed by their parent peaks in mass spectra, i.e.,  $(\eta^2 - 7 - azaNBD)_2Mo(CO)_2$ . The appearance of only one set of NMR signals of compound **3** suggested a symmetrical structure. In <sup>1</sup>H and <sup>13</sup>C NMR spectra, the chemical shifts of H(3), C(2) and C(3) are shifted substantially upfield compared to those of free 7-azaNBD. It indicated that the Mo binds only with C(2)=C(3) but not with C(5)=C(6). To fulfill the requirement of 18 electrons around Mo, the lone pairs of the nitrogen atoms must also act as ligands.

The two units of 7-azaNBD ligands in 4 displayed different characteristics in <sup>1</sup>H and <sup>13</sup>C NMR spectra. The H(3), C(2) and C(3) signals on one unit of 7-aza-NBD exhibited substantial upfield shifts, but not much so on H(5,6) and C(5,6). The corresponding signals on the other unit of 7-azaNBD exhibited just an opposite order. Such a phenomenon suggests that only one of the two  $\pi$ -bonds in each ligand, i.e., C(2)=C(3) in the former and C(5)=C(6) in the latter, is coordinated to the metal. The structure of 4 was confirmed subsequently by single crystal X-ray diffraction analysis. An ORTEP drawing of 4 is shown in Fig. 1. The crystallographic data are listed in Table 4, while selected bond lengths and angles are listed in Table 5. As close examination on bond lengths, we found that the elongation of C=C bond resulted from the coordination to the metal. The bond length of C(2)=C(3)was found to be significantly longer than that of uncoordinated C(5)=C(6) (1.429(8) Å verses 1.303(11) Å for ( $\eta^4$ -norbornadiene) W(CO)<sub>4</sub> [5], but about 0.1 Å shorter than that for M-Cax. The bond lengths and angles around Mo show that the octahedral geometry is substantially distorted. The two bound double bonds facing each other across the Mo are orientated in a perpendicular geometry. The structure also shows that the two tosyl groups are also located in a right angle to each other.

Both <sup>1</sup>H and <sup>13</sup>C NMR spectra of **5** are very similar to those of **4**, which can be regarded as an effect of metal-olefin back bonding. This is also reflected on the shorter bond lengths of Mo–C(2) and Mo–C(3) (2.182(2) and 2.213(6) Å) with respect to Mo–C(5) and Mo–C(6)



Fig. 1. ORTEP view of compound 4.

(2.250(6) and 2.200(6) Å). It can be ascribed to the electron-withdrawing nature of tosyl group, which enhance the degree of backing on C(2) = C(3). The carbonyl groups coordinated to Mo atom are located *cisoid* (86.5°) to each other. The Mo-CO distances are 1.964(7) and 1.959(7) Å, respectively, which are quite close to those of M-Ceq. in cis-( $\eta^4$ -1,5-hexadiene) Mo(CO)<sub>4</sub> [6] cis-( $\eta^3$ -Me<sub>2</sub>POC-HPhH=CH<sub>2</sub>) Mo(CO)<sub>4</sub> [7] and  $cis-\eta^4$ -norbornadiene W(CO)<sub>4</sub> [5], indicating a close similarity between the two. By comparison of the <sup>13</sup>C chemical shifts, we can find that the similar chemical shifts of one azaNBD skeleton suggested the similar bonding fashion. On the other hand, the NMR signals of C(1,3) of second azaNBD unit of 5 showed greater downfield shifts than the corresponding ones of 4 and the NMR signals of C(2,4) work in the other way, indicating the different orientation of azaNBD between two complexes. Two sets of <sup>1</sup>H and <sup>13</sup>C NMR signals were observed for 6, which displays substantial upfield shifts on H(3) and C(2)=C(3) similar to those of 3. It indicated that both 7-azaNBD ligands bind with Mo in the same pattern, i.e., coordination to the double bonds bearing a tosyl group.

## 3. Conclusion

Products distribution of this reaction seems to be governed by the relative degree of steric hindrance. Compounds 4, 5 with relatively low steric hindrance were obtained in major yields, which consist of two tosyl groups well departed from each other. Compounds 3, 6 with higher steric were obtained in low yields, which contain tosyl groups located in close proximity of other groups. The isolation of compound 2 was rather unexpected, considering the relative weak bonding affinity of  $\pi$ -bond to Mo comparing to that of a nitrogen lone pair to Mo.

## 4. Experimental

<sup>1</sup>H and <sup>13</sup>C NMR spectra were obtained on Bruker AC-300 FT spectrometer. Chemical shifts for <sup>1</sup>H and <sup>13</sup>C NMR spectra are recorded downfield from SiMe<sub>4</sub>. IR spectra were recorded on a Perkin–Elmer 882 infrared spectrophotometer; elemental analyses were performed on a Perkin–Elmer 2400EA instrument and FAB mass spectra were carried out on a JEOL SX-102A spectrometer. Melting points were measured by using a Yanamoto MICRO mp apparatus model MP-S3 and were uncorrected. Crystal analysis was performed on Nonius X-ray single crystal diffractometer.

The compounds were sealed in capillary tube under nitrogen atmosphere for mp determinations. 7-Methoxycarbonyl-2-tosyl-7-azanorbornadiene was prepared from the reaction of *N*-methoxycarbonylpyrrole and ethynyl tolyl sulfone according to the literature [8].

Reaction of 7-methoxycarbonyl-2-p-toulenesulfonyl-7azanornadiene and  $Mo(CO)_4(NCMe)_2$ : To a round bottom flask containing Mo(CO)<sub>6</sub> (255 mg, 1.0 mmol) in CH<sub>3</sub>CN (40 mL), a solution of Me<sub>3</sub>NO (188 mg, 2.5 mmol) in CH<sub>3</sub>CN (10 mL) was added slowly through a syringe under a nitrogen atmosphere and room temperature [1f,1g]. After additional stirring for 1 h at same conditions, the solvent was removed under reduced pressure. To it was added a solution of 7-aza-NBD (320 mg, 1 mmol) in CH<sub>2</sub>Cl<sub>2</sub> (40 mL). The solution was stirred under ambient condition for 40 h. After the solvent was removed, the resultant mixture was pre-separated by means of flash column chromatography (silica gel with EtOAc as an eluent) and was then further separated by using HPLC technique (column was packed with silica gel and was eluted with EtOAc/ hexane (9:1) as a mobile phase). All products were crystallized from CH<sub>2</sub>Cl<sub>2</sub>/n-hexane. Their physical data and spectral data are summarized in Tables 1–3.

Crystal data and conditions for crystallographic data collection and structure refinement in the X-ray analysis are listed in Table 4. Some selected data for the bond lengths and bond angles in compound 4 are also listed in Table 5.

## 5. Supplementary material

Crystallographic data for structural analysis have been deposited with the Cambridge Crystallographic Data Centre No. 233340 for 4. Copies of this information may be obtained free of charge from The Director, CCDC, 12 Union Road, e-mail: <u>deposit@ccdc.am.ac.un</u> or www: http://www.ccdc.cam.ac.uk.

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#### References

- [1] (a) D.T. Dixon, P.M. Burkinshaw, J.A.S. Howell, J. Chem. Soc., Dalton Trans. (1980) 2237;
  - (b) K.H. Pannel, A.J. Mayr, R. Hoggard, J.S. McKennis, J.C. Dawson, Chem. Ber. 116 (1983) 230;

- (c) D.T. Dixon, J.C. Kola, J.A.S. Howell, J. Chem. Soc., Dalton Trans. (1984) 1307;
- (d) T.J. Chow, M.-Y. Wu, L.-K. Liu, J. Organomet. Chem. 281 (1985) C33;
- (e) F. Ungvary, J. Shanshool, L. Marko, J. Organomet. Chem. 296 (1985) 155;
- (f) T.J. Chow, C.-Y. Wang, S.-C. Sheu, S.-M. Peng, J. Organomet. Chem. 311 (1986) 339;
- (g) T.J. Chow, Y.-S. Chao, L.-K. Liu, J. Am. Chem. Soc. 109 (1987) 797;
- (h) S.J. Mukerjee, S.P. Nolan, C.D. Hoff, L. de la Vega, Inorg. Chem. 27 (1988) 81;
- (i) F.-W. Grevels, J. Jacke, W.E. Klotzbuecher, K. Schaffner, R.H.
- Hooker, A.J. Rest, J. Organomet. Chem. 382 (1990) 201;
- (j) P.M. Hodges, S.A. Jackson, J. Jacke, M. Poliakoff, J.J. Turner, F.-W. Grevels, J. Am. Chem. Soc. 112 (1990) 1234;
- (k) S. Zhang, G.R. Dobson, Inorg. Chem. 29 (1990) 598;
- (l) R.J. Blau, U. Siriwardane, Organometallics 10 (1991) 1627;
- (m) M.Y. Darensbourg, M. Pala, S.A. Houliston, K.P. Kidwell,
- D. Spencer, S. Chojnacki, J.H. Reibenspies, Inorg. Chem. 31 (1992) 1487;
- (n) J.R. Sowa Jr., J.B. Bonanno, V. Zanotti, R.J. Angelici, J. Inorg. Chem. 31 (1992) 1370;
- (o) G. Bondietti, G. Suardi, R. Ros, R. Roulet, F. Grepioni, D. Braga, Helv. Chim. Acta 76 (1993) 2913;
- (p) M. Akita, M. Terada, N. Ishii, H. Hirakawa, Y. Moro-oka, J. Organomet. Chem. 473 (1994) 175;
- (q) C. Kayran, E. Okan, Z. Naturforsch. B 56 (2001) 281.
- [2] (a) P.S. Lei, P. Vogel, Organometallics 5 (1986) 2500;
  (b) P. Vioget, M. Bonivento, R. Roulet, P. Vogel, Helv. Chim. Acta 67 (1984) 1630;
  - (c) A. Pinkerton, P.A. Carrupt, P. Vogel, T. Boschi, N.H. Thuy, R. Roult, Inorg. Chim. Acta 28 (1978) 123;
  - (d) C.H. Sun, T.J. Chow, J. Organomet. Chem. 333 (1987) C21.
- [3] (a) C.H. Sun, T.J. Chow, J. Chem. Soc., Chem. Commun. (1988) 535;
  - (b) C.H. Sun, T.J. Chow, J. Bull. Inst. Chem. Acad. Sinica 36 (1989) 23;
  - (c) C.H. Sun, T.J. Chow, L.K. Liu, Organometallics 9 (1990) 560;
  - (d) C.H. Sun, J.J. Hwang, T.J. Chow, Bull. Inst. Chem. Acad. Sinica 39 (1992) 13;
  - (e) T.J. Chow, J.J. Hwang, C.H. Sun, M.F. Ding, Organometallics 12 (1993) 3762;
  - (f) C.H. Sun, N.C. Shang, L.S. Liou, J.C. Wamg, J. Organomet. Chem. 481 (1994) 179;
  - (g) J.J. Hwang, M.F. Ding, Y.S. Wen, T.J. Chow, J. Chem. Soc., Dalton Trans. (1998) 119;
  - (h) C.H. Sun, S.Y. Wu, L.S. Liou, J.C. Wang, J. Chin. Chem. Soc. 45 (1998) 564.
- [4] C.M. Lukehart, Fundamental Transition Metal Organometallic Chemistry, Brooks/Cole Publishing Company, Belmont, CA, 1985, p. 78.
- [5] J.D. Atwood, Inorganic and Organometallic Reaction Mechanisms, Brooks/Cole Publishing Company, Belmont, CA, 1985, p. 54.
- [6] R.J. Blau, U. Siriwardane, Organometallics 10 (1991) 1627.
- [7] F.-W. Grevels, J. Jacke, P. Betz, C. Krueger, Y.-H. Tsay, Organometallics 8 (1989) 293.
- [8] Z. Chen, M.L. Trudell, Tetrahedron Lett. 35 (1994) 9649.