

# THE PHOSPHINE-EXCHANGE REACTION WITH AN EQUIMOLAR MIXTURE OF $[(\eta^5\text{-C}_5\text{H}_5)\text{Fe}(\text{CO})_2\text{PPh}_3]^+[\text{PF}_6]^-$ AND $\text{P}(2\text{-C}_4\text{H}_3\text{O})_3$ ( $\text{C}_4\text{H}_3\text{O} = \text{FURANYL}$ )

O.G. Adeyemi<sup>1,2\*</sup> and L.-K.Liu<sup>2,3</sup>

<sup>1</sup>Department of Chemistry, University of Ilorin, Ilorin, Nigeria;

<sup>2</sup>Institute of Chemistry, Academia Sinica, Taipei, Taiwan, ROC

<sup>3</sup>Department of Chemistry, National Taiwan University, Taipei, Taiwan, ROC

(Received August 11, 2000; revised January 17, 2001)

**ABSTRACT.** A trace amount of *n*-BuLi at -78 °C initiates a chemical attack on  $[(\eta^5\text{-C}_5\text{H}_5)\text{Fe}(\text{CO})_2\text{I}]$  by the ligands ( $\text{PPh}_3$  and  $\text{P}(2\text{-C}_4\text{H}_3\text{O})_3$ ) leading to the formation of cationic species,  $[(\eta^5\text{-C}_5\text{H}_5)\text{Fe}(\text{CO})_2\text{PPh}_3]^+[\text{I}]^-$  and  $[(\eta^5\text{-C}_5\text{H}_5)\text{Fe}(\text{CO})_2\text{P}(2\text{-C}_4\text{H}_3\text{O})_3]^+[\text{I}]^-$ . Anion exchange could be conveniently carried out by dissolving the iodides in a solutions of excess  $\text{NH}_4\text{PF}_6$  in  $\text{CH}_3\text{CN}$ , to afford yellow solids  $[(\eta^5\text{-C}_5\text{H}_5)\text{Fe}(\text{CO})_2\text{PPh}_3]^+[\text{PF}_6]^-$  and  $[(\eta^5\text{-C}_5\text{H}_5)\text{Fe}(\text{CO})_2\text{P}(2\text{-C}_4\text{H}_3\text{O})_3]^+[\text{PF}_6]^-$ . The determination of the equilibrium constant *K* was carried out in a single experiment in an NMR tube, utilizing MeLi as reductant in the phosphine exchange reaction. The slight difference in donor capability of the two ligands ( $\text{PPh}_3$  and  $\text{P}(2\text{-C}_4\text{H}_3\text{O})_3$ ) was observed as supporting evidence for their stereo-electronic properties.

**KEY WORDS:** Phosphine-exchange reaction,  $[(\eta^5\text{-C}_5\text{H}_5)\text{Fe}(\text{CO})_2\text{I}]$ ,  $\text{PPh}_3$ ,  $\text{P}(2\text{-C}_4\text{H}_3\text{O})_3$ ,  $[(\eta^5\text{-C}_5\text{H}_5)\text{Fe}(\text{CO})_2\text{PPh}_3]^+[\text{I}]^-$ ,  $[(\eta^5\text{-C}_5\text{H}_5)\text{Fe}(\text{CO})_2\text{P}(2\text{-C}_4\text{H}_3\text{O})_3]^+[\text{I}]^-$ ,  $[(\eta^5\text{-C}_5\text{H}_5)\text{Fe}(\text{CO})_2\text{PPh}_3]^+[\text{PF}_6]^-$ ,  $[(\eta^5\text{-C}_5\text{H}_5)\text{Fe}(\text{CO})_2\text{P}(2\text{-C}_4\text{H}_3\text{O})_3]^+[\text{PF}_6]^-$ .

## INTRODUCTION

Ligand exchange reactions in organometallic compounds catalysed by electron transfer chain (ETC) have been studied in several systems. A good example is the enhanced reactivity of an iron(0) complex when the iron complex is reduced to Fe(I). Darchen [1] studied the electroreduction of  $\eta^5$ -cyclopentadienyl iron  $\eta^6$ -arene cation, which produces a radical of the same formula. The behaviour of this radical depends on the nature of the substituent on the rings and on the medium. Also Maroney and Trogler [2] studied the reduction of the same compound and the co-ordination of the radical formed with solvent molecules. The increasing stability of the product formed from  $(\eta^5\text{-cyclopentadienyl})(\eta^6\text{-arene}) \text{Fe(I)}$  as a function of the solvent was used: acetonitrile or pyridine < dimethylformamide < acetone or methylene chloride.

Most ligand substitution reactions of 19e complexes are due to the fast 17/19e interconversion and therefore follow a dissociative mechanism [2-10]. Recently, Peng and Liu [11] have worked on the phosphine-exchange induced intramolecular substitution reaction of  $[(\eta^5\text{-C}_5\text{H}_5)\text{Fe}(\text{CO})_2(\mu\text{-}\eta^1\text{-}\eta^1\text{-dppe})]^+_{2+}$ . It was stated that, in  $\text{CH}_3\text{CN}$  a mixture of  $[(\eta^5\text{-C}_5\text{H}_5)\text{Fe}(\text{CO})_2(\mu\text{-}\eta^1\text{-}\eta^1\text{-dppe})]^+_{2+}[\text{PF}_6]_2^-$  and dppe in a 1:1 molar ratio, the  $[(\eta^5\text{-C}_5\text{H}_5)\text{Fe}(\text{CO})_2(\mu\text{-}\eta^1\text{-}\eta^1\text{-dppe})]^+$  cation radical forms immediately by initiating the reaction with a small amount of  $(\eta^5\text{-C}_5\text{H}_5)_2\text{Co}$ . This leads to rapid phosphine exchange in which dppe likely replaces (the remotely positively charged)  $[(\eta^5\text{-C}_5\text{H}_5)\text{Fe}(\text{CO})_2(\eta^1\text{-dppe})]^+$  in the  $[(\eta^5\text{-C}_5\text{H}_5)\text{Fe}(\text{CO})_2(\mu\text{-}\eta^1\text{-}\eta^1\text{-dppe})]^+$  cation radical, resulting in the 18e  $[(\eta^5\text{-C}_5\text{H}_5)\text{Fe}(\text{CO})_2(\eta^1\text{-dppe})]^+$  cation and the 19e  $[(\eta^5\text{-C}_5\text{H}_5)\text{Fe}(\text{CO})_2(\eta^1\text{-dppe})]^\cdot$  radical.

\*To whom correspondence should be addressed at Department of Chemistry, University of Ilorin, P.M.B. 1515, Ilorin, Nigeria. E-mail: gabisola@ilorin.skannet.com

In this study, the stereo-electronic properties of the ligands ( $\text{PPh}_3$  and  $\text{P}(2\text{-C}_4\text{H}_3\text{O})_3$ ) (tri(2-furanyl)phosphine) was studied. The slight difference in donor capability of the ligands was measured directly in the equilibrium of phosphine replacement reaction.

## EXPERIMENTAL

*General procedure.* All experimental manipulations were performed under an atmosphere of pre-purified nitrogen, utilizing standard Schlenk techniques and a double manifold vacuum line. A nitrogen atmosphere glovebox was also employed. All solvents were freshly distilled from appropriate drying agents [12]. For instance, THF,  $\text{Et}_2\text{O}$  and *n*-hexane were dried over sodium benzophenone ketal, while  $\text{CH}_3\text{CN}$  was dried over  $\text{P}_2\text{O}_5$  and  $\text{CaH}_2$  was used to dry  $\text{CH}_2\text{Cl}_2$ .

Melting points were determined on a Yanaco MPL melting point apparatus and the values are uncorrected. The  $^{31}\text{P}$  NMR spectra were obtained on a Bruker AC 200/AC 300 spectrometer employing 85%  $\text{H}_3\text{PO}_4$  as an external standard ( $^{31}\text{P}$ ,  $\delta$  0.0). Infra red spectra were recorded in  $\text{CH}_2\text{Cl}_2$  (unless otherwise stated) using  $\text{CaF}_2$  optics on a Perkin-Elmer (FT-IR) Paragon 1000 spectrometer. The  $^1\text{H}$  NMR and  $^{13}\text{C}$  NMR spectra were obtained on a Bruker AC 200/AC 300/AMX 400 spectrometers. Chemical shifts are relative to the residual resonances of  $\text{CDCl}_3$  ( $^1\text{H}$ ,  $\delta$  7.24,  $^{13}\text{C}$ ,  $\delta$  77.0). Low resolution mass spectra were recorded on a VG 70-250 mass spectrometer, using the fast atomic bombardment technique. Chemical analyses were performed on a Perkin-Elmer 2400 CHN elemental analyser.

Monopyridyldiphenylphosphine [13], dipirydylphenylphosphine [14], tripyridylphosphine [15] and  $(\eta^5\text{-C}_5\text{H}_5)\text{Fe}(\text{CO})_2\text{I}$  [16] were prepared according to the known procedure. All other reagents were obtained from commercial sources, e.g. Aldrich chemical Co. TCI Co, Merck Co. Across Chemical, R.D.H. and Strem, and the chemical were used without further purification.

*Preparation of  $[(\eta^5\text{-C}_5\text{H}_5)\text{Fe}(\text{CO})_2\text{PPh}_3]^+[\text{PF}_6]^-$  [17].* Dry THF of 30 mL was added to a mixture of  $(\eta^5\text{-C}_5\text{H}_5)\text{Fe}(\text{CO})_2\text{I}$  (0.304 g, 1 mmol) and  $\text{PPh}_3$  (0.262 g, 1 mmol). The temperature was maintained at  $-78^\circ\text{C}$ , then a trace amount of *n*-BuLi (1.6 M in hexane) was added and the solution was stirred for 15 min. THF was added to the resultant yellow solid and then filtered. The solid was re-dissolved in  $\text{CH}_3\text{CN}$  along with an excess amount of  $\text{NH}_4\text{PF}_6$ . Excess water was added to obtain a crystalline yellow solid which was filtered and washed with water and  $\text{Et}_2\text{O}$  to produce  $[(\eta^5\text{-C}_5\text{H}_5)\text{Fe}(\text{CO})_2\text{PPh}_3]^+[\text{PF}_6]^-$ . Yield: 0.47 g, 81%; m.p. 258-260  $^\circ\text{C}$ ; IR ( $\text{CH}_2\text{Cl}_2$ ):  $\nu(\text{CO})$  2057 (s), 2014 (s)  $\text{cm}^{-1}$ ;  $^{31}\text{P}$  NMR ( $d_6$ -acetone):  $\delta$  62.4 (s), -143.2 (heptet);  $^1\text{H}$  NMR ( $d_6$ -acetone):  $\delta$  7.4-7.6 (m, 15H, Ph), 5.28 (s, 5H, Cp).

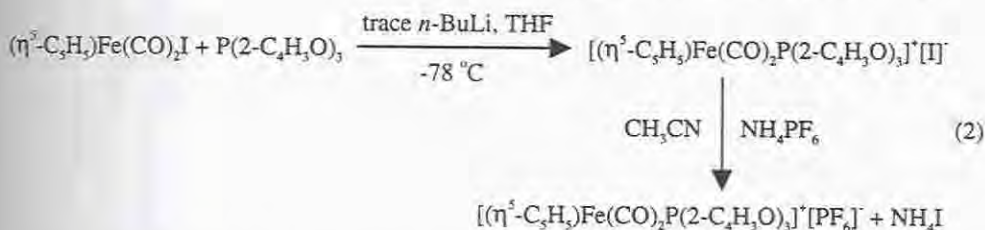
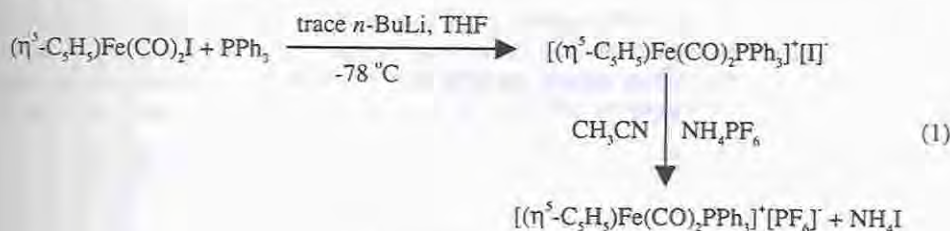
*Preparation of  $[(\eta^5\text{-C}_5\text{H}_5)\text{Fe}(\text{CO})_2\text{P}(2\text{-C}_4\text{H}_3\text{O})_3]^+[\text{PF}_6]^-$ .* A mixture of  $(\eta^5\text{-C}_5\text{H}_5)\text{Fe}(\text{CO})_2\text{I}$  (0.155 g, 0.5 mmol) and  $\text{P}(2\text{-C}_4\text{H}_3\text{O})_3$  (0.133 g, 0.5 mmol) in 5 mL (THF) was maintained at  $-78^\circ\text{C}$ . Further treatment of this mixture followed the procedures used for the synthesis of the  $\text{PPh}_3$  analogue. Yield: 0.17 g, 61%; m.p. 242  $^\circ\text{C}$ ; IR ( $\text{CH}_2\text{Cl}_2$ ):  $\nu(\text{CO})$  2070 (s), 2030 (s)  $\text{cm}^{-1}$ ;  $^{31}\text{P}$  NMR ( $d_6$ -acetone):  $\delta$  21.2 (s), -143.9 (heptet,  $J_{\text{PF}} = 2829$  Hz);  $^1\text{H}$  NMR ( $d_6$ -acetone):  $\delta$  6.79- 8.15 (b, 9H, furyl), 5.77 (b, 5H, Cp);  $^{13}\text{C}$  NMR ( $d_6$ -acetone):  $\delta$  208.61 (d, CO), 113.14-152.18 (m, furyl), 89.32 (s, Cp); MS ( $m/z$ ): 410 ( $\text{M}^+ + 1\text{-PF}_6^-$ ); anal. calcd. for  $\text{C}_{10}\text{H}_{14}\text{FeO}_5\text{F}_6\text{P}_2$ : C 41.16, H 2.53%; found: C 41.16, H 2.41%.

*Phosphine exchange reaction between  $[(\eta^5\text{-C}_5\text{H}_5)\text{Fe}(\text{CO})_2\text{PPh}_3]^+[\text{PF}_6]^-$  and tri(2-furanyl)phosphine.*  $[(\eta^5\text{-C}_5\text{H}_5)\text{Fe}(\text{CO})_2\text{PPh}_3]^+[\text{PF}_6]^-$  (0.045 mmol) and  $\text{P}(2\text{-C}_4\text{H}_3\text{O})_3$  (0.045 mmol) were dissolved in  $\text{CH}_2\text{Cl}_2$  (0.5 mL) in a 5 mm NMR tube with the inner tube filled with 0.54

mmol  $\text{PPh}_3(\text{O})$  (triphenylphosphine oxide) in  $\text{CDCl}_3$  (0.5 mL). The 1:1 intensity integration ratios were observed for the cation and the free ligand. In the outer part of the NMR tube containing the cation and the ligand, a trace amount of MeLi was introduced to the solution to give a phosphine exchange. The reaction was monitored by  $^{31}\text{P}$  NMR spectrum (Figure 1).

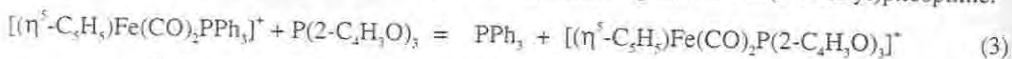
## RESULTS AND DISCUSSION

Electron-transfer chain catalysis (pioneered by Taube [18]) in inorganic chemistry has been applied to the preparation of organometallic complexes, utilizing the greatly enhanced reactivity of organometallic 17e and 19e radicals in comparison to their 16e and 18e analogues [19, 20-23]. The  $\text{PPh}_3$  substitution for CO in  $[(\eta^5\text{-C}_5\text{H}_5)\text{Fe}(\text{CO})_2]^+$  proceeds via a 17e-19e pathway after electrochemical or chemical initiation and yields  $[(\eta^5\text{-C}_5\text{H}_5)\text{Fe}(\text{CO})_2\text{PPh}_3]^+$  quantitatively [24]. Also, the reaction of 1:1  $[(\eta^5\text{-C}_5\text{H}_5)\text{Fe}(\text{CO})_2\text{I}]/\text{PPh}_3$  or  $\text{P}(\text{2-C}_4\text{H}_3\text{O})_3$  in THF at  $-78^\circ\text{C}$ , initiated by a small amount of reducing agent, e.g. diluted BuLi also follows the 17e-19e pathway and gives quantitative precipitates of  $[(\eta^5\text{-C}_5\text{H}_5)\text{Fe}(\text{CO})_2\text{PPh}_3]^+[\text{I}]^-$  and  $[(\eta^5\text{-C}_5\text{H}_5)\text{Fe}(\text{CO})_2\text{P}(\text{2-C}_4\text{H}_3\text{O})_3]^+[\text{I}]^-$ . Anion exchange was successfully carried out by dissolving the precipitates in a solution of  $\text{NH}_4\text{PF}_6$  in acetonitrile and crystallization in excess water gave  $[(\eta^5\text{-C}_5\text{H}_5)\text{Fe}(\text{CO})_2\text{PPh}_3]^+[\text{PF}_6]^-$  and  $[(\eta^5\text{-C}_5\text{H}_5)\text{Fe}(\text{CO})_2\text{P}(\text{2-C}_4\text{H}_3\text{O})_3]^+[\text{PF}_6]^-$ .



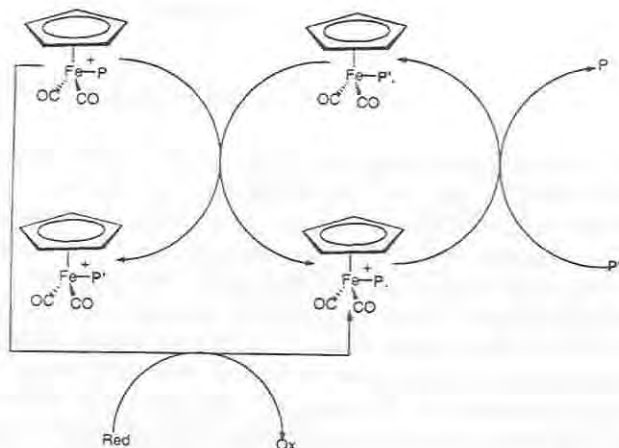
The carbonyl stretching frequencies among the cationic products differ significantly. The compounds  $[(\eta^5\text{-C}_5\text{H}_5)\text{Fe}(\text{CO})_2\text{PPh}_3]^+$  and  $[(\eta^5\text{-C}_5\text{H}_5)\text{Fe}(\text{CO})_2\text{P}(\text{2-C}_4\text{H}_3\text{O})_3]^+$  have two carbonyl resonances at 2057 and 2014  $\text{cm}^{-1}$  and 2070 and 2030  $\text{cm}^{-1}$ , respectively. It was observed that the two absorptions in the complexes were shifted somewhat to lower wave numbers when compared with the starting material  $[(\eta^5\text{-C}_5\text{H}_5)\text{Fe}(\text{CO})_2\text{I}]$  (2041 and 1996  $\text{cm}^{-1}$ ). Perhaps the differences reflect the different degree of back bonding to the carbon monoxide ligand. The  $^1\text{H}$  NMR resonance of the cation reflects characteristic  $(\eta^5\text{-C}_5\text{H}_5)$ -ring proton slightly above  $\delta$  5 [25]. Such down field chemical shifts indicate that the electron retained on the  $(\eta^5\text{-C}_5\text{H}_5)$ -ring is lower than those of the neutral complexes. The anion  $\text{PF}_6^-$  does not appear to have significant influence on the chemical shift of the cationic complexes. The  $^{31}\text{P}$  NMR results shows a significant decrease in chemical shift values from  $\text{PPh}_3$  ( $\delta$  62.4) to  $\text{P}(\text{2-C}_4\text{H}_3\text{O})_3$  ( $\delta$  21.2) which indeed could translate to a decrease in the donor capability of the phosphines.

With  $[(\eta^5\text{-C}_5\text{H}_5)\text{Fe}(\text{CO})_2\text{PPh}_3]^+[\text{PF}_6]^-$ , the 17e-19e pathway enables one to study the replacement of  $\text{PPh}_3$  on  $[(\eta^5\text{-C}_5\text{H}_5)\text{Fe}(\text{CO})_2\text{PPh}_3]^+$  by  $\text{P}(\text{2-C}_4\text{H}_3\text{O})_3$ . Scheme I shows such ETC reaction. Organophosphines are used in many metal mediated reactions [26]. As a consequence, chemist have been interested in deducing their stereo-electronic properties [26], the best known parameters being the cone angle  $\theta$  and the electronic parameters  $\chi$  [27]. Also a good parameter, the  $\text{p}K_a$  value for  $\text{HPR}_3^+$  depends on the interaction between the phosphorus and  $\text{H}^+$ , a hard acid [28, 29]. Such an interaction is not generally considered the same as that between the phosphorus ligand and a low valent metal centre in organometallic complexes. The tri(2-furanyl)phosphine ( $\text{P}(\text{2-C}_4\text{H}_3\text{O})_3$ ) is without readily available  $\text{p}K_a$ ,  $\chi$  and  $E^\circ$  values for the evaluation of its stereoelectronic properties. The only starting point is that the  $^{31}\text{P}$  NMR chemical shifts are more up field ( $\delta$  -76), but this does not necessarily give detailed information about its properties. Therefore, to evaluate any differences in the donor capabilities of  $\text{PPh}_3$  and  $\text{P}(\text{2-C}_4\text{H}_3\text{O})_3$ , direct measurement of an equilibrium constant in the phosphine replacement reaction on  $(\eta^5\text{-C}_5\text{H}_5)\text{Fe}(\text{CO})_2$ -phosphine complex was carried out. In the reaction, a 1:1 mixture of  $[(\eta^5\text{-C}_5\text{H}_5)\text{Fe}(\text{CO})_2\text{PPh}_3]^+/\text{P}(\text{2-C}_4\text{H}_3\text{O})_3$  was used, which show a  $^{31}\text{P}$  NMR spectrum with respective peak at  $\delta$  63 and -76 and intensity ratios of *ca.* 4.5 and 4.4 (Figure 1a). After addition of few drops of  $\text{MeLi}$ , (an initiator to activate the 17e-19e pathway) the mixture reveals a  $^{31}\text{P}$  NMR spectrum as given in Figure 1b. The change of the spectrum is both instantaneous and complete. Two new species are formed after addition of  $\text{MeLi}$ , the peak at  $\delta$  -4.7 is indicative of released  $\text{PPh}_3$ , and the resonance at  $\delta$  21.2 shows the formation of  $[(\eta^5\text{-C}_5\text{H}_5)\text{Fe}(\text{CO})_2\text{P}(\text{2-C}_4\text{H}_3\text{O})_3]^+$ . The intensity ratio for  $[(\eta^5\text{-C}_5\text{H}_5)\text{Fe}(\text{CO})_2\text{PPh}_3]^+$ ,  $[(\eta^5\text{-C}_5\text{H}_5)\text{Fe}(\text{CO})_2\text{P}(\text{2-C}_4\text{H}_3\text{O})_3]^+$ ,  $\text{PPh}_3$  and  $\text{P}(\text{2-C}_4\text{H}_3\text{O})_3$  was shown in Figure 1b. The ratios stay the same after 24 h, i.e. the phosphine exchange reaction with a radical process proceeds to completion in a time scale of less than a minute. It may be concluded that the  $\text{PPh}_3$  is a better donor ligand than tri(2-furanyl)phosphine:



$$K = \frac{[(\eta^5\text{-C}_5\text{H}_5)\text{Fe}(\text{CO})_2\text{P}(\text{2-C}_4\text{H}_3\text{O})_3]^+[\text{PPh}_3]}{[(\eta^5\text{-C}_5\text{H}_5)\text{Fe}(\text{CO})_2\text{PPh}_3]^+[\text{P}(\text{2-C}_4\text{H}_3\text{O})_3]} \quad (4)$$

$$K = (0.5)(0.9)/(4.1)(2.5) = 0.04.$$



Scheme I. Electron-transfer chain catalytic phosphine-exchange reaction.

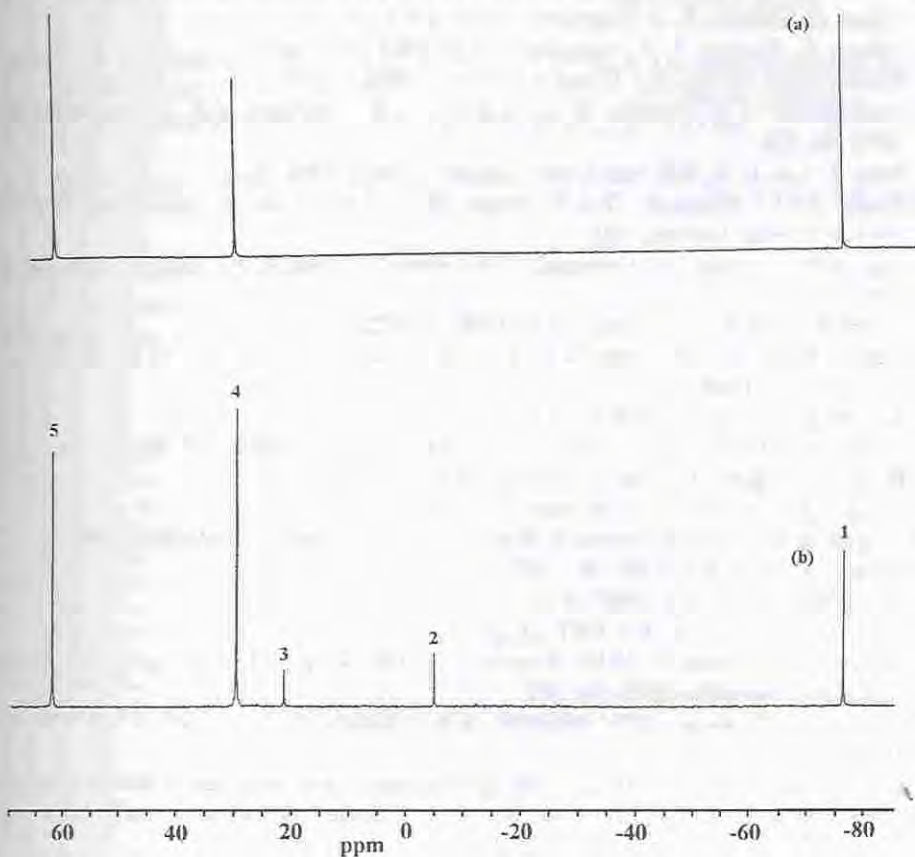


Figure 1.  $^{31}\text{P}$  NMR spectra of (a) before and (b) after phosphine-exchange reaction with 1:1 mixture of  $[(\eta^5\text{-C}_5\text{H}_5)\text{Fe}(\text{CO})_2\text{PPh}_3]^+[\text{PF}_6]^-$  and  $\text{P}(\text{2-C}_4\text{H}_9\text{O})_3$ . (1)  $\text{P}(\text{2-C}_4\text{H}_9\text{O})_3$ , (2)  $\text{PPh}_3$ , (3)  $[(\eta^5\text{-C}_5\text{H}_5)\text{Fe}(\text{CO})_2\text{P}(\text{2-C}_4\text{H}_9\text{O})_3]^+$ , (4)  $\text{PPh}_3(\text{O})$ , (5)  $[(\eta^5\text{-C}_5\text{H}_5)\text{Fe}(\text{CO})_2\text{PPh}_3]^+$ .

### ACKNOWLEDGEMENTS

The financial support from the Institute of Chemistry and National Science Council Taipei, Taiwan, ROC, is acknowledged. OGA thank University of Ilorin for staff development and senate research grant award.

### REFERENCE

1. Darchen, A. *J. Organomet. Chem.* **1986**, 302, 389.
2. Maroney, M.J.; Trogler, W.C. *J. Am. Chem. Soc.* **1984**, 106, 4144.
3. Narayanan, B.A.; Amatore, C.; Kochi, J.K. *J. Chem. Soc., Chem. Commun.* **1983**, 397.
4. Connor, J.A.; Overton, C.; El Murr, N. *J. Organomet. Chem.* **1984**, 277, 277.
5. Alegria, A.E.; Lozada, O.; Rivera, H.; Sanchez, J. *J. Organomet. Chem.* **1985**, 281, 229.
6. Miholova, D.; Vlcek, A.A. *J. Organomet. Chem.* **1985**, 279, 317.

7. Albeti, A.; Hudson, A. *J. Organomet. Chem.* **1983**, 241, 313.
8. Alberti, A.; Hudson, A. *J. Organomet. Chem.* **1983**, 248, 199.
9. Albers, M.O.; Coville, N.J. *Coord. Chem. Rev.* **1984**, 53, 227.
10. Nesmeyanov, A.N.; Volenau, N.A.; Shilotseva, L.S.; Petrakova, V.A. *J. Organomet. Chem.* **1973**, 61, 329.
11. Peng, J.; Liu, L.-K. *Bull. Inst. Chem. Academia Sinica.* **1998**, 45, 27.
12. Perrin, D.D.; Armarego, W.L.F.; Perrin, D.R. *Purification of Laboratory Chemicals* Pergamon Press: Oxford; 1988.
13. Maisonne, A.; Farr, J.P.; Olmstead, M.M.; Hunt, C.T.; Balch, A.L. *Inorg. Chem.* **1982**, 21, 3961.
14. Mann, F.G.; Watson, J. *J. Org. Chem.* **1948**, 13, 502.
15. Kurtev, K.; Ribola, D.; Jones, R.A.; Cole-Hamilton, D.J.; Wilkinson, G.W. *J. Chem. Soc. Dalton Trans.* **1980**, 55.
16. Kleinberg, J. *Inorg. Syn.* **1963**, 7, 110.
17. Barder, T.J.; Tetrack, S.M.; Walton, R.A. *J. Am. Chem. Soc.* **1983**, 105, 4090.
18. Rich, R.L.; Taube, H. *J. Am. Chem. Soc.* **1954**, 76, 2608.
19. Tyler, D.R. *Prog. Inorg. Chem.* **1988**, 36, 125.
20. Trogler, W. C. Ed. *Organometallic Radical Process*, Elsevier: Amsterdam, 1990.
21. Astruc, D. *Chem. Rev.* **1988**, 88, 1189.
22. Baird, M.C. *Chem. Rev.* **1988**, 88, 1217.
23. Tyler, D.R. *Acc. Chem. Res.* **1991**, 24, 325.
24. Pevear, K.A.; Banaszak, M.M.; Carpenter, H.G.B.; Rieger, A.L.; Rieger, P.H.; Sweigart, D.A. *Organometallics* **1995**, 14, 512.
25. Arewgoda, M.; Rieger, P.H.; Robinson, B.H.; Simpson, J.; Visco, S.J. *J. Am. Chem. Soc.* **1982**, 104, 5633.
26. E.C. Alyca in *Catalytic Aspects of Metal Phosphine Complexes*, Series 196 of *Advances in Chemistry*; Meck, D.W. (Ed); American Chemical Society: Washington, D.C.; 1982.
27. Tolman, C.A. *Chem. Rev.* **1977**, 77, 313.
28. Allman, T.; Goel, R.G. *Can. J. Chem.* **1982**, 60, 716.
29. Handerson, W.A.; Steuli, C.A. *J. Am. Chem. Soc.* **1960**, 82, 5791.