

## The Use of Supported Transition Metals and Metal Oxides as Catalysts for the Metal Carbonyl Substitution Reaction

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Supported transition metals (Pt, Pd, Ru, Rh) and PdO and PtO<sub>2</sub> catalyse the reaction  $M-CO + L \rightarrow M-L + CO$  (L = isonitrile, group 5 donor ligand) and readily give complexes such as  $Mo(CO)_2(PhCH_2NC)_4$ ,  $Mn_2(CO)_9(C_6H_{11}NC)$ ,  $Ir_4(CO)_6(Bu^tNC)_6$ , and  $Re_2(CO)_8(PMePh_2)_2$  in high yield; the catalyst supports also show mild catalytic behaviour.

The metal carbonyl substitution reaction is important in synthetic organometallic chemistry<sup>1</sup> and catalysis.<sup>2</sup> Thermal<sup>3</sup> and photochemical<sup>4</sup> procedures have been used to bring about the reaction  $M-CO + L \rightarrow M-L + CO$  but more recently alternative procedures using chemical reagents (*e.g.*  $Me_3NO$ <sup>5</sup>) or catalysts<sup>6</sup> have also been used. Our recent study on the use of  $[(\eta^5-C_5H_5)Fe(CO)_2]_2$  as a catalyst<sup>7</sup> suggested to us that reagents capable of electron-transfer processes (*e.g.* heterogeneous hydrogenation catalysts)<sup>8</sup> should also catalyse the CO substitution reaction. The model reaction  $Fe(CO)_4(Bu^tNC) + Bu^tNC \rightarrow Fe(CO)_3(Bu^tNC)_2$ <sup>9</sup> was used to explore this possibility and our results, indicating high catalytic activity for the Pt and Pd catalysts, are reported in Table 1. The use of Pd/C for the reaction  $M(CO)_n + ^{13}CO \rightarrow M(CO)_{n-1}(^{13}CO)$  has been reported<sup>10</sup> but extension to ligand substitution reactions in general has not previously been considered.

The substitution reaction can readily be extended to a wide range of isonitriles, RNC, *e.g.* with R =  $C_6H_{11}$ ,  $PhCH_2$ , and 2,6- $Me_2C_6H_3$  and, further multiple CO substitution to give  $Fe(CO)_{5-n}(2,6-Me_2C_6H_3NC)_n$ <sup>9</sup> ( $n = 1-5$ ) has been achieved in the presence of Pd, Pd/C, and Pd/CaCO<sub>3</sub>. The reaction between  $Fe(CO)_5$  (20 mmol) and  $PPh_3$  (10 mmol) in toluene (10 ml) is also catalysed by Pd and Pt catalysts to give  $Fe(CO)_4(PPh_3)_4$ <sup>11</sup> in typically > 90% yield (Pd/C, 2.5 h; Pd/CaCO<sub>3</sub>, 3 h; PdO, 10 h; PtO<sub>2</sub>, 15 h).

Extension of the use of Pt and Pd catalysts to other metal carbonyl systems has resulted in a significant breakthrough in the facile high-yield synthesis of substituted zerovalent isonitrile<sup>12</sup> and group 5 donor ligand complexes. This is exemplified by the complexes (mono- to tetra-metallic) listed in Table 2. All the new complexes have been characterized by i.r. and n.m.r. spectroscopy (Table 2) and elemental analyses. Reactions are reproducible and no evidence for isonitrile polymerization, as previously reported, *e.g.* in the synthesis of  $Os_3(CO)_{12-n}(RNC)_n$ <sup>13</sup> derivatives, has been observed.

The reaction  $Fe(CO)_4(RNC) + RNC \rightarrow Fe(CO)_3(RNC)_2$  (R = 2,6- $Me_2C_6H_3$ ,  $Bu^t$ ), in the presence of PdO, PtO<sub>2</sub>, or Pd/CaCO<sub>3</sub> as catalyst, has been found to be inhibited by galvinoxyl and hydroquinone and enhanced by illumination (500 W lamp). We thus suspect that the mechanism is similar to that of the  $[(\eta^5-C_5H_5)Fe(CO)_2]_2$  catalysed reaction<sup>7</sup> (to be discussed further).

Control reactions, in the presence of the catalyst support only, have revealed that certain supports also show mild catalytic activity. For instance, the reaction between  $M(CO)_6$  and  $Bu^tNC$  (1 mmol reactants, refluxing benzene) to give  $M(CO)_5(Bu^tNC)$  (M = Mo, W) is catalysed by activated carbon obtained from a variety of sources. For M = Mo yields of > 90% product were obtained when the activated carbons Norit W20, Bergbau PK221, and Amborsorb XE348 were used. Although we have been unable to establish the

**Table 1.** The effect of catalysts on the reaction  $Fe(CO)_4(Bu^tNC) + (Bu^tNC) \rightarrow Fe(CO)_3(Bu^tNC)_2$ <sup>a</sup>.

Catalyst	Reaction time/min <sup>b</sup>	Catalyst	Reaction time/min <sup>b</sup>
Thermal blank	120	Pt/C (5%)	5
Pd	4	Pt/Al <sub>2</sub> O <sub>3</sub> (5%)	5
Pd/C (5%)	2	Rh/C (5%)	45 (50) <sup>c</sup>
Pd/Al <sub>2</sub> O <sub>3</sub> (5%)	2	Ru/C (5%)	<sup>d</sup> (35) <sup>c</sup>
Pd/Al <sub>2</sub> O <sub>3</sub> (0.1%)	4	Ru/Al <sub>2</sub> O <sub>3</sub> (5%)	15 (2) <sup>c</sup>
Pd/BaSO <sub>4</sub> (5%)	2	PdO	2
Pd/CaCO <sub>3</sub> (5%)	2	PtO <sub>2</sub>	20

<sup>a</sup> Reaction conditions  $Fe(CO)_4(Bu^tNC)$  (1 mmol);  $Bu^tNC$  (1 mmol), catalyst (20 mg), and benzene (reflux) (10 ml). <sup>b</sup> As determined by i.r. spectroscopy. <sup>c</sup> Reaction time after catalyst activation: 12 h at 300 °C under N<sub>2</sub> followed by 3 h at 300 °C under H<sub>2</sub>. <sup>d</sup> No catalysis observed.

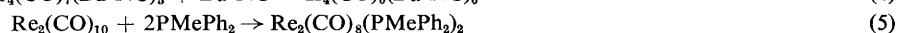
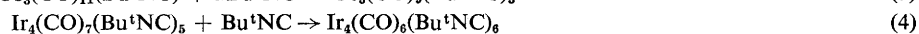
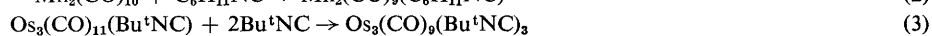
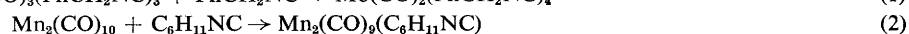
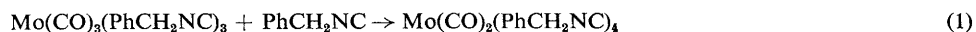
**Table 2.** Some representative examples of metal carbonyl substitution reactions catalysed by supported metals or metal oxides.

Reaction <sup>a</sup>	Catalyst	Solvent	Reaction time	Yield/%	I.r./cm <sup>-1b</sup>	Product	N.m.r. (δ) <sup>c</sup>
(1) <sup>d</sup>	Pd/C, PdO	Toluene (reflux)	3 h	> 60	2155, 2110(sh), 2096, 2064, 1981, 1943		7.3 (Ph), 4.78, and 4.75 (CH <sub>2</sub> )
(2)	Pd/CaCO <sub>3</sub> , Pd/BaSO <sub>4</sub>	Benzene (25 °C)	10 min	80	2175, 2088, 2028, 1995, 1970, 1960 <sup>e</sup>		1.3 and 1.1 (CH <sub>2</sub> ) <sup>f</sup>
(3) <sup>d, g</sup>	Pd/C	Benzene (45 °C)	10 min	70	2165, 2145, 2055, 2035, 2014, 1988, 1973, 1955, 1936 <sup>h</sup>		1.5 (Me)
(4) <sup>d, g</sup>	Pd/C	Toluene (reflux)	10 min	60	2150, 1965, 1768		1.47 (Me)
(5) <sup>d</sup>	Pd/C	Xylene (reflux)	2 h	80	2064, 2009, 1976(sh), 1952, 1912(sh) <sup>i</sup>		7.4 (Ph), 2.47 (Me) <sup>j</sup>

<sup>a</sup> Typical reactions were carried out on a 1 mmol scale for reactants and *ca.* 20 mg catalyst (5–10% loading) in 10–20 ml of solvent.

<sup>b</sup> Recorded in CHCl<sub>3</sub>; 2200–1600 cm<sup>-1</sup> region. <sup>c</sup> Recorded in CDCl<sub>3</sub> relative to tetramethylsilane. <sup>d</sup> The earlier members of the series can also be prepared in the presence of catalysts. <sup>e</sup> Recorded in hexane. <sup>f</sup> Recorded in C<sub>6</sub>D<sub>6</sub>. <sup>g</sup> 0.1 mmol of reactants. <sup>h</sup> Ref. 13.

<sup>i</sup> Ref. 14. <sup>j</sup> J(P–H) 7.2 Hz.



active component(s) in the carbon, *e.g.* by analysis of the ash content or preparation of activated carbons with added ingredients such as Fe and Ti, we have established that crystalline aluminosilicates also catalyse the substitution reaction, for example  $\text{Mo(CO)}_6 + \text{Bu}^t\text{NC} \rightarrow \text{Mo(CO)}_5(\text{Bu}^t\text{NC})$ . Zeolites containing exchanged transition metals have also shown mild catalytic activity for the above reaction *e.g.* RuNaY (0.68% Ru) and NiNaY (2.52% Ni).

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