

TITLE

5 PROCESS FOR MAKING 5-CYANOVALERIC
 ACID, ADIPIC ACID OR DIMETHYL ADIPATE

FIELD OF THE INVENTION

10 The present invention relates to a process for the
conversion of (1) 3-pentenitrile to 5-cyanovaleric
acid or its corresponding esters, (2) 3-pentenoic acid
to adipic acid and (3) methyl 3-pentenoate to dimethyl
adipate.

BACKGROUND OF THE INVENTION

15 Two processes are known in the art for the
preparation of caprolactam from butadiene. The first
process involves the following steps: (1) stepwise
addition of two equivalents of hydrogen cyanide to
butadiene to produce adiponitrile, (2) partial
20 hydrogenation of adiponitrile to form 6-
aminocapronitrile, (3) separation of 6-
aminocapronitrile from fully hydrogenated
hexamethylenediamine and unreacted adiponitrile, and
(4) hydrolysis of 6-aminocapronitrile and cyclization
25 of the hydrolysis product to produce caprolactam.

 The second process involves the following steps:
(1) carbonylation of butadiene to methyl 3-pentenoate,
(2) hydroformylation of methyl 3-pentenoate to methyl
5-formylvalerate, (3) reductive amination of methyl 5-
30 formylvalerate to methyl 6-aminocaproate, and (4)
cyclization of methyl 6-aminocaproate to caprolactam.

 It would be desirable to develop a process that
produces fewer by-products than the above processes and
involves fewer reaction steps. A process that

satisfies these needs could be based on the carbonylation of 3-pentenitrile to 5-cyanovaleric acid or its corresponding esters. The process to
5 produce caprolactam would involve the steps of: (1) hydrocyanation of butadiene to 3-pentenitrile, (2) carbonylation of 3-pentenitrile to 5-cyanovaleric acid or ester, and (3) hydrogenation and cyclization of 5-cyanovaleric acid or ester to caprolactam.

10 In order to develop a successful process, an active, selective catalyst that operates under mild conditions for the carbonylation of 3-pentenitrile is needed. Previous attempts to produce methyl 5-cyanovalerate or 5-cyanovaleric acid from 3-
15 pentenitrile were based on the use of a cobalt catalyst. US patent 5,434,290 discloses the use of a cobalt catalyst, an activating solvent comprising carbonic diesters, carbamates or ureas and CO pressures between 210 to 270 bar to convert 3-pentenitrile to
20 methyl 5-cyanovalerate. US patent 4,508,660 discloses a similar process, but using sulfones as the preferred solvent and CO pressures between 14 to 35 MPa. The rates of carbonylation reported in this patent are quite low, the turnover frequency calculated for
25 example 2 of U.S. Patent 4,508,660 gives 1.52 mol/mol-hour. A similar situation is described in U.S. patent 4,933,483.

Palladium-based catalysts for the carbonylation of olefins and diolefins are known in the art. U.S.
30 Patent 5,028,734 discloses a process for the selective carbonylation of conjugated dienes in the presence of an alcohol and a catalyst system comprising a halide-free palladium salt, a bidentate phosphine ligand and a protonic acid with a pKa value greater than 3. PCT

patent application WO 00/56695 discloses a process for the carbonylation of conjugated dienes by reaction with CO and alcohol in the presence of a catalyst system including a source of palladium cations, a phosphorus-containing ligand of structure X^1-R-X^2 and a source of anions. The preferred ligands are based on a 9-phosphabicyclononyl group for X^1 and X^2 and a simple bridge for R. PCT patent application WO97/38964 describes the use of the same catalyst system for the carbonylation of ethylenically unsaturated compounds.

PCT patent application WO 98/42717 describes a catalyst of the formula $R^1>P-R^2-PR^3R^4$ for the carbonylation of terminal and internal olefins. The $R^1>P$ moiety is a substituted 2-phosphatricyclo[3.3.1.1{3,7}]decyl group where one or more of the carbon atoms are replaced by heteroatoms, in particular oxygen. Comparisons are made between phosphines such as $(Me_3C)P(CH_2)_3P(CMe_3)$ (DTBPP) and 1,3-P,P'-di(2-phospha-1,3,5,7-tetramethyl-6,9,10-trioxatricyclo[3.3.11{3.7}]decyl propane (DPA3). Carbomethoxylation of an internal-C14 olefin feed with a palladium-based catalyst using DPA3 as a ligand gives linear methyl ester with 78% selectivity at an average rate of 120 mol/mol-hour. In contrast, using DTBPP as ligand under identical conditions gives only an average rate of 5 mol/mol-hour.

PCT patent application WO96/19434 and *Chem Comm.*, 1999, 20, 1877-1878 describe the use of bidentate phosphines such as (di-t-butyl phosphino)-o-xylene for the carbonylation of ethylene to methylpropanoate. The patent application describes catalysts using these bidentate phosphines as being unable to carbonylate propene. One skilled in the art might reason that if

such catalysts are able to carbonylate ethylene, but fail to carbonylate propene at any appreciable rate, then these same catalysts would be inactive for the carbonylation of internal olefins. Surprisingly, these catalysts are able to convert an internal olefin, namely 3-pentenitrile, to the corresponding linear carboxylic acid, namely 5-cyanovaleric acid (or its alkyl esters). Additionally these catalysts are able to convert 3-pentenoic acid to adipic acid, and to convert methyl 3-pentenoate to dimethyl adipate.

SUMMARY OF THE INVENTION

The present invention is a process for producing

(1) a compound of the formula $\text{NC-CH}_2\text{-CH}_2\text{-CH}_2\text{-CH}_2\text{-CO}_2\text{R}'$, wherein R' is H or C_1 to C_{12} alkyl, or

(2) adipic acid, or

(3) dimethyl adipate,

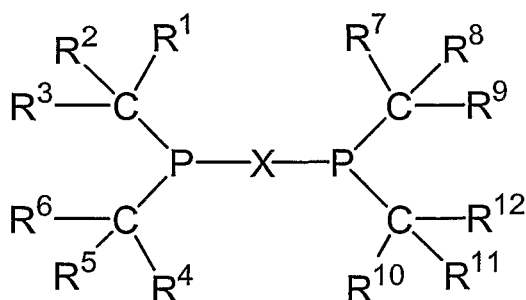
comprising: contacting a substrate selected from the group consisting of (A) (B) and (C) wherein substrate (A) is 3-pentenitrile, wherein substrate (B) is 3-pentenoic acid, and wherein substrate (C) is methyl 3-pentenoate, with a nucleophile (a), (b), or (c), respectively,

wherein nucleophile (a) is alcohol or water,

wherein nucleophile (b) is water and

wherein nucleophile (c) is methanol, and carbon monoxide, in the presence of a Group VIII metal;

a ligand of the formula



wherein

- 5 X is a substituted or unsubstituted bridging group selected from the group consisting of a divalent aryl, a divalent alkylene group, and a divalent combination of alkylene and aromatic groups; and
- wherein R^1 , R^4 , R^7 , and R^{10} , independently are H,
- 10 or C_1 to C_{12} alkyl;
- provided that R^2 , R^3 , R^5 , R^6 , R^8 , R^9 , R^{11} , and R^{12} , independently are C_1 to C_{12} alkyl or cycloalkyl,
- wherein R^2 and R^3 ; R^5 and R^6 ; R^8 and R^9 ; and R^{11} and R^{12} may be taken together to form a cycloalkyl group;
- 15 and
- a promoter, said promoter comprising a strong acid having a pKa in water of less than 1 and, when the nucleophile is water, at least one carboxylic acid.

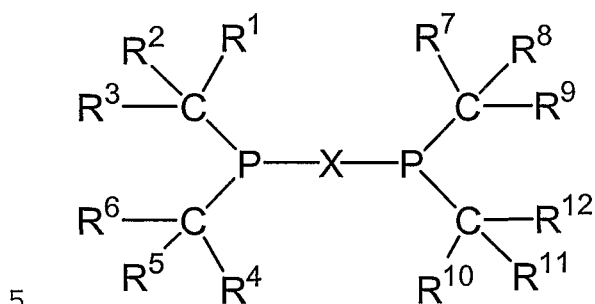
20 DETAILED DESCRIPTION OF THE INVENTION

Disclosed herein is a process for preparing important, commercially useful compounds, each having various functionality. The catalyst, which is the metal plus the ligand, involved in the process of the present

25 invention are very active and selective for the carbonylation of 3-pentenitrile when compared with other prior art catalysts based on ligands such as 1,3-P,P'-di(2-phospha-1,3,5,7-tetramethyl-6,9,10-trioxatricyclo[3.3.11{3.7}]decyl propane and 1,2-

30 P,P'-bis(1,5-dimethyl, 9-phosphabicyclononyl)ethane.

The ligands of the present invention are bidentate phosphines of the general formula shown below.



wherein

X is a substituted or unsubstituted bridging group selected from the group consisting of a divalent aryl, a divalent alkylene group, and a divalent combination of alkylene and aromatic groups; and

wherein R^1 , R^4 , R^7 , and R^{10} , independently are H, or C_1 to C_{12} alkyl;

provided that R^2 , R^3 , R^5 , R^6 , R^8 , R^9 , R^{11} , and R^{12} , independently are C_1 to C_{12} alkyl or cycloalkyl,

wherein R^2 and R^3 ; R^5 and R^6 ; R^8 and R^9 ; and R^{11} and R^{12} may be taken together to form a cycloalkyl group.

Examples of suitable X groups include, but are not limited to, the following:

20

$-(CH_2)_n-$

1,2-cyclohexyl

25

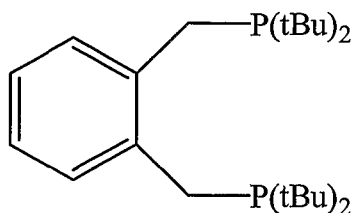
$o-C_6H_4$

$-CHCH_3-CHCH_3-$

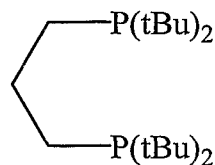
ortho- $CH_2-C_6H_4-$

30

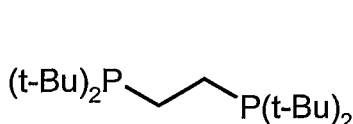
Examples of suitable specific ligands include Ligands 1-5, shown below, wherein (tBu=tert-butyl).



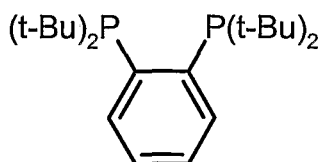
Ligand 1



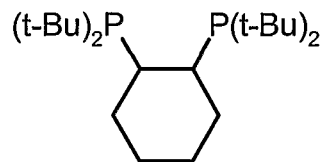
Ligand 2



Ligand 3



Ligand 4



Ligand 5

Suitable Group VIII metals include cobalt, nickel,
 10 palladium, rhodium and platinum. Particularly
 preferred is palladium. The palladium catalyst used in
 the process of the invention may be provided in the
 form of a palladium complex of the specified bidentate
 phosphine. It may also be generated in situ by adding
 15 a source of palladium and a source of the bidentate
 phosphine to the reaction. Suitable sources of
 palladium include palladium carboxylates, such as
 palladium acetate, propionate, butyrate or benzoate and
 palladium salts of mineral acids. Further sources
 20 include palladium complexes such as palladium
 acetylacetonate, tris(dibenzylideneacetone)
 dipalladium.

Some examples of suitable nucleophiles are water
 and primary and secondary alcohols, such as straight
 25 chain and branched lower alkanols.

Some examples of suitable specific promoters
 include strong acids (pKa in water of less than 1),
 such as methanesulphonic acid, chlorosulphonic acid,
 benzene sulphonic acid, trifluoromethane sulphonic

acid. When the nucleophile is water, and the substrate is 3-pentenitrile, the strong acid must be combined with at least one carboxylic acid, such as acetic acid, propionic acid, benzoic acid, o-toluoic acid, m-toluoic acid, or p-toluoic acid. The addition of at least one carboxylic acid can be used with methyl-3-pentenoate, but it is not necessary for the process to achieve the conversion.

10 The process may be carried out at a temperature in the range of about 80 degrees C to about 150 degrees C and a carbon monoxide partial pressure in the range of about 200 to about 2000 psi.

 Suitable solvents are one or more aprotic solvents such as ethers, e.g. diethyl ether, diethylene glycol dimethyl ether, anisole; aromatic compounds, e.g. benzene, toluene, o-xylene, m-xylene, p-xylene; alkanes, e.g. hexane, heptane; nitriles, e.g. acetonitrile, benzonitrile, adiponitrile; and esters, e.g. methyl benzoate, ethyl acetate. The reaction also can be carried out using the substrates and alcohol and/or water as the solvent.

 The molar ratio of the substrate and the alcohol or water can vary widely in the range of 1:1 to about 1:50, preferably between 1:1 to about 1:10. The molar ratio of the substrate to the Group VIII metal can vary widely in the range about 10:1 to about 10000:1, preferably in the range of about 100:1 to about 2000:1. The molar ratio of the ligand to the Group VIII metal can vary widely in the of range 1:1 to about 50:1, preferably in the range of 1:1 to about 5:1. The molar ratio of the strong acid to the Group VIII metal can vary widely in the range 1:1 to about 50:1, preferably in the range 1:1 to about 5:1. The molar ratio of the

carboxylic acid to the Group VIII metal can vary between widely in the range about 0:1 to about 10000:1, preferably in the range of about 1:1 to about 2000:1.

5 Examples of suitable bidentate ligands are bis(di-t-butyl phosphino)-o-xylene and bis (di-t-butyl phosphino) propane. Bis(di-t-butyl phosphino)-o-xylene has been described in *J.Chem. Soc., Chem. Comm*, 1976, 365, and it is made by treating o-BrCH₂C₆H₄CH₂Br with
10 HP(t-Bu)₂ and subsequent reaction with a base. Bis (di-t-butyl phosphino) propane has been described in *J.Chem. Soc., Dalton Trans.*, 1991, 863, and it is made by reacting 1,3-dibromopropane with LiP(t-Bu)₂ in tetrahydrofuran as solvent.

15 The carbonylation process of the present invention can be performed batchwise, semi-continuously or continuously. Preferably a continuous manner of operation is used because it allows for higher molar ratios of substrate to the Group VIII metal and lower
20 residence times. The products of the carbonylation of 3-pentenitrile with methanol are methyl 5-cyanovalerate, methyl 4-cyano-2-methyl butyrate, and methyl 3-cyano-2-ethyl propionate. The products of the carbonylation of 3-pentenoic acid with water include
25 adipic acid, 2-methylglutaric acid, and 2-ethylsuccinic acid. The products of the carbonylation of methyl 3-pentenoate with methanol include dimethyl adipate, methyl 2-methylglutarate, and methyl 2-ethylsuccinate.

30 The invention is illustrated by the following non-limiting examples, in which the following terms are defined as indicated:

linearity: $100 * [\text{Moles of linear isomer}] / [\text{Sum of all isomers}]$

conversion: $100 * [\text{Substrate}] / [\text{Substrate}]_0$ where

$[\text{Substrate}]_0$ is the initial concentration of substrate

selectivity: $100 * [\text{Moles of linear product}] / [\text{Sum of all}$

5 products detected by GC analysis]

TOF (turnover frequency): $[\text{Moles of linear}$

product] / $[\text{Moles of palladium}] [\text{hour}]$

EXAMPLES

10 Example 1: Synthesis of Ligand 1

Di-t-butyl phosphine (5.0 g, 0.0342 mol) was added dropwise to a solution of α, α' -dibromo-o-xylene (4.51 g, 0.0171 mol) in 50 ml acetone and left to stir for 36 hours at ambient temperature in a nitrogen drybox.

15 After removing the acetone under vacuum, the resulting white solid was rinsed with ether. Under nitrogen, a solution of sodium acetate (12 g) in water (30 ml) was added to a suspension of the dry white solid in ether (150 ml). The product was extracted under nitrogen
20 with ether (2 x 150 ml) and dried over NaSO_4 . The combined ether layers were vacuum-stripped to yield 1.5 g of yellow solid (22% yield). ^{31}P NMR (C_6D_6): 25.1 ppm.

25 Example 2: Synthesis of Ligand 2

Lithium di-t-butylphosphine was prepared by reacting di-t-butylphosphine (5.0g, 0.034 mol) with n-butyl lithium (21.0 ml, 0.034 mol) at ambient temperature under nitrogen with stirring overnight.

30 Four grams of the white solid were recovered by filtration (78% yield). 1,3 Dibromopropane (1.27 g, 0.00629 mol) was added dropwise to a solution of lithium di-t-butylphosphine (2.0 g, .0132 mol) in 50 ml THF and left to stir at ambient temperature overnight.

After completely removing the THF, the lithium salts were precipitated from the residue with minimal pentane. The salts were filtered out completely and the pentane was reduced to yield 1.5 g of colorless oil (69 % yield). ^{31}P NMR (C_6D_6): 27.3 ppm.

Example 3: Carbomethoxylation of 3-pentenitrile with Ligand 1

A 100 ml Hastelloy B air motor stirred Parr (brand name) reactor was loaded with a solution of the following composition: 25 g MeOH, 52 mg palladium acetate, 32 g 3-pentenitrile, 29 μl methanesulfonic acid, 0.511 g o-dichlorobenzene and 0.135g Ligand 1. After pressurizing the reactor to 500 psi of CO at the final temperature of 100 $^{\circ}\text{C}$, the reaction was monitored by GC during the five hour run. Results for linearity, conversion, selectivity and turnover frequency (mol/mol h) are listed in Table 1.

Table 1

Time [min]	Linearity	Conversion	Selectivity	TOF
0.00	98.50	38.05	59.88	
15.00	98.38	54.97	65.25	2336.15
30.00	98.31	63.88	67.88	1419.55
45.00	98.26	68.56	70.60	1064.50
60.00	98.22	71.95	73.25	877.53
90.00	98.15	77.39	78.61	672.62
120.00	98.10	81.85	83.28	567.61
180.00	98.03	89.63	90.18	447.07
240.00	97.99	94.74	94.10	371.72
300.00	97.98	97.60	96.25	313.75

Example 4: Carbomethoxylation of 3-pentenitrile with Ligand 2

Ligand 2 (0.122 g) was substituted for Ligand 1 in the procedure outlined in Example 3. Results for linearity, conversion, selectivity and turnover frequency (mol/mol h) are listed in Table 2.

Table 2

Time [min]	Linearity	Conversion	Selectivity	TOF
0.00	94.55	19.24	42.53	
15.00	93.87	30.58	52.42	323.20
30.00	93.69	47.50	57.70	282.29
45.00	93.61	59.31	61.13	251.21
60.00	93.60	63.96	63.03	210.66
90.00	93.54	69.91	66.51	162.56
120.00	93.58	72.70	68.92	132.14
180.00	93.52	78.28	73.58	101.10
240.00	93.54	81.92	72.22	83.80

Comparative Example A

1,3-P,P'-di(2-phospha-1,3,5,7-tetramethyl-6,9,10-trioxatricyclo[3.3.1.1{3.7}]propane (0.149 g), prepared as described in Example 1 of PCT patent application WO 98/42717, was substituted for Ligand 1 in the procedure outlined in Example 3. Results for linearity, conversion selectivity and turnover frequency (mol/mol h) are listed in Table 3.

Table 3

Time [min]	Linearity	Conversion	Selectivity	TOF
0.00	89.87	26.79	84.30	0.00
15.00	89.85	37.11	85.71	641.43
30.00	89.78	43.72	86.72	385.20
45.00	89.73	49.34	86.95	292.66
60.00	89.53	52.72	86.99	242.50
90.00	89.63	59.94	87.38	182.93
120.00	89.71	63.98	87.53	145.51
180.00	89.72	68.22	87.78	104.46
240.00	89.70	71.39	87.89	81.88
300.00	89.70	72.93	87.87	67.25

Example 5: Hydrocarboxylation of 3-pentenitrile with**5 Ligand 1**

A 100 ml Hastelloy B air motor stirred Parr (brand name) reactor was loaded with a solution of the following composition: 34 g diglyme, 54 mg palladium acetate, 10 g 3-pentenitrile, 46 mg methanesulfonic acid, 0.5 g o-dichlorobenzene, 0.143 g Ligand 1, 5 ml degassed water and 10g degassed acetic acid. After pressurizing the reactor to 500 psi of CO at the final temperature of 100 °C, the reaction was monitored by GC during the five hour run. Results for linearity, conversion, selectivity and turnover frequency (mol/mol h) are listed in Table 4.

Table 4

Time [min]	Linearity	Conversion	Selectivity	TOF
15.00	98.57	11.74	53.56	130.94
30.00	98.02	22.30	70.47	150.90
45.00	97.51	31.62	85.69	152.10
60.00	97.43	36.21	88.49	131.10
90.00	99.32	48.45	94.73	121.99
120.00	99.33	50.37	95.79	102.62
360.00	97.39	66.16	95.19	44.05

Comparative Example B

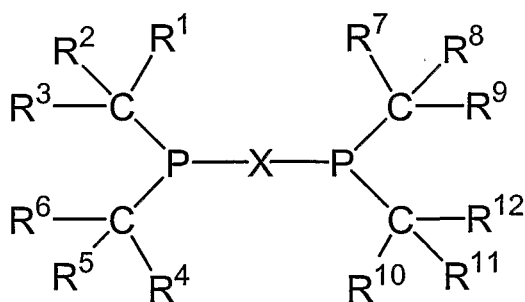
- 5 1,3-P,P'-di(2-phospha-1,3,5,7-tetramethyl-6,9,10-trioxatricyclo[3.3.1.1{3.7}]propane (0.149 g), prepared as described in Example 1 of PCT patent application 98/42717, was substituted for Ligand 1 in the procedure outlined in Example 5. Results for
- 10 linearity, conversion, selectivity and turnover frequency (mol/mol h) are listed in Table 5.

Table 5

Time [min]	Linearity	Conversion	Selectivity	TOF
15.00	86.08	1.45	71.96	89.04
30.00	86.34	4.75	77.06	68.09
45.00	86.64	5.48	78.72	57.18
60.00	86.91	8.29	80.37	55.32
90.00	87.00	11.25	81.66	50.96
120.00	87.06	16.72	82.72	48.69
180.00	87.23	22.54	84.08	43.81
240.00	87.16	28.02	84.51	37.77
300.00	87.14	29.18	84.79	31.52
360.00	87.10	27.87	85.00	26.51

CLAIMSWHAT IS CLAIMED IS:

- 5 1. The present invention is a process for
producing (1) a compound of the formula $\text{NC-CH}_2\text{-CH}_2\text{-CH}_2\text{-CH}_2\text{-CO}_2\text{R}'$, wherein R' is H or C_1 to C_{12} alkyl, or
(2) adipic acid, or
(3) dimethyl adipate,
10 comprising:contacting a substrate selected from the
group consisting of (A) (B) and (C)
wherein substrate (A) is 3-pentenitrile,
wherein substrate (B) is 3-pentenoic acid, and
wherein substrate (C) is methyl 3-pentenoate,
15 with a nucleophile (a), (b), or (c), respectively,
wherein nucleophile (a) is alcohol or water,
wherein nucleophile (b) is water and
wherein nucleophile (c) is methanol,
and carbon monoxide, in the presence of
20 a Group VIII metal;
a ligand having the formula



- 25 wherein
X is a substituted or unsubstituted bridging group
selected from the group consisting of a divalent aryl,
a divalent alkylene group, and a divalent combination
of alkylene and aromatic groups; and

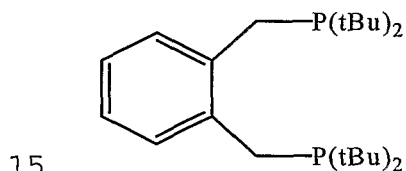
wherein R^1 , R^4 , R^7 , and R^{10} , independently are H, or C_1 to C_{12} alkyl;

provided that R^2 , R^3 , R^5 , R^6 , R^8 , R^9 , R^{11} , and R^{12} ,
 5 independently are C_1 to C_{12} alkyl or cycloalkyl,

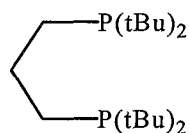
wherein R^2 and R^3 ; R^5 and R^6 ; R^8 and R^9 ; and R^{11} and R^{12} may be taken together to form a cycloalkyl group; and

a promoter, said promoter comprising a strong acid
 10 having a pKa in water of less than 1 and, when the nucleophile is water, at least one carboxylic acid.

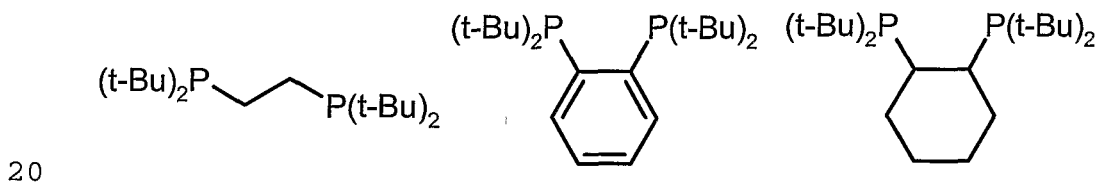
2. The process of claim 1 wherein the ligand is selected from the group consisting of the



Ligand 1



Ligand 2



Ligand 3

Ligand 4

Ligand 5.

3. The process of claim 1 wherein said Group VIII metal is palladium.

25 4. The process of claim 1 wherein said promoter is methanesulphonic acid.

5. The process of claim 1 wherein at least one of R^1 , R^4 , R^7 , and R^{10} is H, C_1 , C_2 , or C_6 to C_{12} alkyl.

6. The process of claim 1 wherein the substrate
 30 is (a) or (c).

7. The process of claim 6 wherein the nucleophile is water and the substrate is 3-pentenitrile, said process further comprising adding
5 a carboxylic acid.

8. The process of claim 7 wherein the carboxylic acid is acetic acid..