Office de la Propriété Intellectuelle du Canada
Un organisme d'Industrie Canada

Canadian Intellectual Property Office
An agency of Industry Canada

CA 2319801 C 2006/10/03

(11)(21) 2 319 801

(12) BREVET CANADIEN
CANADIAN PATENT

(13) C

(86) Date de dépôt PCT/PCT Filing Date: 1999/02/01
(87) Date publication PCT/PCT Publication Date: 1999/08/05
(45) Date de délivrance/Issue Date: 2006/10/03
(85) Entrée phase nationale/National Entry: 2000/08/01
(86) N° demande PCT/PCT Application No.: US 1999/002090
(87) N° publication PCT/PCT Publication No.: 1999/038832
(30) Priorité/Priority: 1998/02/02 (US09/017,456)

(51) Cl.Int./Int.Cl. *C07C 45/50* (2006.01), *B01J 31/40* (2006.01), *B01J 31/18* (2006.01), *C07B 63/00* (2006.01), *C07C 45/80* (2006.01), *C07C 51/373* (2006.01), *C07C 51/48* (2006.01), *C07C 59/147* (2006.01), *C07F 9/02* (2006.01)

(72) Inventeurs/Inventors:
ARGYROPOULOS, JOHN N., US;
BRYANT, DAVID ROBERT, US;
MORRISON, DONALD LEE, US;
STOCKMAN, KENNETH ELWOOD, US

(73) Propriétaire/Owner:
UNION CARBIDE CHEMICALS & PLASTICS TECHNOLOGY CORPORATION, US

(74) Agent: SMART & BIGGAR

(54) Titre : PROCEDES DE SEPARATION AMELIORES
(54) Title: IMPROVED SEPARATION PROCESSES

(57) Abrégé/Abstract:
This invention relates to a process for separating one or more products from a reaction product fluid comprising a metal-organophosphorus ligand complex catalyst, optionally free organophosphorus ligand, a nonpolar solvent and said one or more products, wherein said process comprises (1) mixing said reaction product fluid with a polar solvent to obtain by phase separation a nonpolar phase comprising said metal-organophosphorus ligand complex catalyst, optionally free organophosphorus ligand and said nonpolar solvent and a polar phase comprising said one or more products and polar solvent, and (2) recovering said polar phase from said nonpolar phase; wherein said organophosphorus ligand has a partition coefficient between the nonpolar solvent and the polar solvent of greater than about 5, and said one or more products have a partition coefficient between the polar solvent and the nonpolar solvent of greater than about 0.5.

PCT WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 :
C07C 45/50, 45/80, C07F 9/02, C07C 51/373, 51/48, 59/147, C07B 63/00, B01J 31/40, 31/18

A1

(11) International Publication Number: WO 99/38832

(43) International Publication Date: 5 August 1999 (05.08.99)

(21) International Application Number: PCT/US99/02090

(22) International Filing Date: 1 February 1999 (01.02.99)

(30) Priority Data:
09/017,456 2 February 1998 (02.02.98) US

(71) Applicant: UNION CARBIDE CHEMICALS & PLASTICS TECHNOLOGY CORPORATION [US/US]; 39 Old Ridgebury Road, Danbury, CT 06817–0001 (US).

(72) Inventors: ARGYROPOULOS, John, N.; 35 Michael Street, Scott Depot, WV 25560 (US). BRYANT, David, Robert; 1201 Shady Way, South Charleston, WV 25303 (US). MORRISON, Donald, Lee; 170 Roxalana Hills Drive, Dunbar, WV 25064 (US). STOCKMAN, Kenneth, Elwood; 901 Ridgemont Road, Charleston, WV 25314 (US).

(74) Agent: WIGGINS, Karen, Johnson; Union Carbide Chemicals & Plastics Technology Corporation, 39 Old Ridgebury Road, Danbury, CT 06817–0001 (US).

(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, GH, GM, HU, ID, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published
With international search report.
Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.

(54) Title: IMPROVED SEPARATION PROCESSES

(57) Abstract

This invention relates to a process for separating one or more products from a reaction product fluid comprising a metal–organophosphorus ligand complex catalyst, optionally free organophosphorus ligand, a nonpolar solvent and said one or more products, wherein said process comprises (1) mixing said reaction product fluid with a polar solvent to obtain by phase separation a nonpolar phase comprising said metal–organophosphorus ligand complex catalyst, optionally free organophosphorus ligand and said nonpolar solvent and a polar phase comprising said one or more products and polar solvent, and (2) recovering said polar phase from said nonpolar phase; wherein said organophosphorus ligand has a partition coefficient between the nonpolar solvent and the polar solvent of greater than about 5, and said one or more products have a partition coefficient between the polar solvent and the nonpolar solvent of greater than about 0.5.

D-17782

IMPROVED SEPARATION PROCESSES

Brief Summary of the Invention

Technical Field

This invention relates to improved metal-organophosphorus ligand complex catalyzed processes. More particularly this invention relates to metal-organophosphorus ligand complex catalyzed processes in which the desired product can be selectively extracted and separated from the reaction product fluid by phase separation.

Background of the Invention

It is known in the art that various products may be produced by reacting one or more reactants in the presence of an metal-organophosphorus ligand complex catalyst. However, stabilization of the catalyst and organophosphorus ligand remains a primary concern of the art. Obviously catalyst stability is a key issue in the employment of any catalyst. Loss of catalyst or catalytic activity due to undesirable reactions of the highly expensive metal catalysts can be detrimental to the production of the desired product. Moreover, production costs of the product obviously increase when productivity of the catalyst decreases.

For instance, a cause of organophosphorus ligand degradation and catalyst deactivation of metal-organophosphorus

ligand complex catalyzed hydroformylation processes is due in part to vaporizer conditions present during, for example, in the vaporization employed in the separation and recovery of the aldehyde product from the reaction product mixture. When using a vaporizer to facilitate separation of the aldehyde product of the process, a harsh environment of a high temperature and a low carbon monoxide partial pressure than employed during hydroformylation is created, and it has been found that when a organophosphorus promoted rhodium catalyst is placed under such vaporizer conditions, it will deactivate at an accelerated pace with time. It is further believed that this deactivation is likely caused by the formation of an inactive or less active rhodium species. Such is especially evident when the carbon monoxide partial pressure is very low or absent. It has also been observed that the rhodium becomes susceptible to precipitation under prolonged exposure to such vaporizer conditions.

For instance, it is theorized that under harsh conditions such as exist in a vaporizer, the active catalyst, which under hydroformylation conditions is believed to comprise a complex of rhodium, organophosphorus ligand, carbon monoxide and hydrogen, loses at least some of its coordinated carbon monoxide, thereby providing a route for the formation of such a catalytically inactive or less active rhodium. Accordingly, a successful method for preventing and/or lessening such degradation of the organophosphorus ligand and deactivation of the catalyst as occur under harsh separation conditions in a vaporizer would be highly desirable to the art.

Disclosure of the Invention

It has now been discovered that in metal-organophosphorus ligand complex catalyzed processes, the desired product can be selectively extracted and separated from the reaction product fluid by phase separation. By the practice of this invention, it is now possible to separate the desired product from the reaction

product fluid without the need to use vaporization separation and the harsh conditions associated therewith. This invention provides a highly desirable separation method which prevents and/or lessens degradation of the organophosphorus ligand and deactivation of the catalyst as occur under harsh conditions with vaporization separation.

This invention relates in part to a process for separating one or more products from a reaction product fluid comprising a metal-organophosphorus ligand complex catalyst, optionally free organophosphorus ligand, a nonpolar solvent, a polar solvent and said one or more products, wherein said process comprises (1) mixing said reaction product fluid to obtain by phase separation a non-polar phase comprising said metal-organophosphorus ligand complex catalyst, optionally free organophosphorus ligand and said nonpolar solvent and a polar phase comprising said one or more products and polar solvent, and (2) recovering said polar phase from said nonpolar phase; wherein said organophosphorus ligand has a partition coefficient between the nonpolar solvent and the polar solvent of greater than about 5, and said one or more products have a partition coefficient between the polar solvent and the nonpolar solvent of greater than about 0.5.

This invention also relates in part to a process for separating one or more products from a reaction product fluid comprising a metal-organophosphorus ligand complex catalyst, optionally free organophosphorus ligand, a nonpolar solvent and said one or more products, wherein said process comprises (1) mixing said reaction product fluid with a polar solvent to obtain by phase separation a non-polar phase comprising said metal-organophosphorus ligand complex catalyst, optionally free organophosphorus ligand and said nonpolar solvent and a polar phase comprising said one or more products and polar solvent, and (2) recovering said polar phase from said nonpolar phase; wherein said organophosphorus ligand has a partition coefficient between the nonpolar solvent and the polar solvent of greater than about 5, and said one or more products have a partition

coefficient between the polar solvent and the nonpolar solvent of greater than about 0.5.

This invention further relates in part to a process for producing one or more products comprising: (1) reacting one or more reactants in the presence of a metal-organophosphorus ligand complex catalyst, optionally free organophosphorus ligand, a nonpolar solvent and a polar solvent to form a multiphase reaction product fluid; and (2) separating said multiphase reaction product fluid to obtain one phase comprising said one or more reactants, metal-organophosphorus ligand complex catalyst, optionally free organophosphorus ligand and nonpolar solvent and at least one other phase comprising said one or more products and polar solvent; wherein said organophosphorus ligand has a partition coefficient between the nonpolar solvent and the polar solvent of greater than about 5, and said one or more products have a partition coefficient between the polar solvent and the nonpolar solvent of greater than about 0.5.

This invention yet further relates in part to a process for producing one or more products comprising: (1) reacting one or more reactants in the presence of a metal-organophosphorus ligand complex catalyst, optionally free organophosphorus ligand and a nonpolar solvent to form a reaction product fluid; (2) mixing said reaction product fluid with a polar solvent to form a multiphase reaction product fluid; and (3) separating said multiphase reaction product fluid to obtain one phase comprising said one or more reactants, metal-organophosphorus ligand complex catalyst, optionally free organophosphorus ligand and nonpolar solvent and at least one other phase comprising said one or more products and polar solvent; wherein said organophosphorus ligand has a partition coefficient between the nonpolar solvent and the polar solvent of greater than about 5, and said one or more products have a partition coefficient between the polar solvent and the nonpolar solvent of greater than about 0.5.

This invention also relates in part to a process for producing aldehydes comprising: (1) reacting an olefinic unsaturated compound with carbon monoxide and hydrogen in the presence of a metal-organophosphorus ligand complex catalyst, optionally free organophosphorus ligand, a nonpolar solvent and a polar solvent to form a multiphase reaction product fluid; and (2) separating said multiphase reaction product fluid to obtain one phase comprising said olefinic unsaturated compound, metal-organophosphorus ligand complex catalyst, optionally free organophosphorus ligand and nonpolar solvent and at least one other phase comprising said aldehydes and polar solvent; wherein said organophosphorus ligand has a partition coefficient between the nonpolar solvent and the polar solvent of greater than about 5, and said aldehydes have a partition coefficient between the polar solvent and the nonpolar solvent of greater than about 0.5.

This invention further relates in part to a process for producing aldehydes comprising: (1) reacting an olefinic unsaturated compound with carbon monoxide and hydrogen in the presence of a metal-organophosphorus ligand complex catalyst, optionally free organophosphorus ligand and a nonpolar solvent to form a reaction product fluid; (2) mixing said reaction product fluid with a polar solvent to form a multiphase reaction product fluid; and (3) separating said multiphase reaction product fluid to obtain one phase comprising said olefinic unsaturated compound, metal-organophosphorus ligand complex catalyst, optionally free organophosphorus ligand and nonpolar solvent and at least one other phase comprising said aldehydes and polar solvent; wherein said organophosphorus ligand has a partition coefficient between the nonpolar solvent and the polar solvent of greater than about 5, and said aldehydes have a partition coefficient between the polar solvent and the nonpolar solvent of greater than about 0.5.

According to one aspect of the present invention, there is provided a process for separating one or more products from a reaction product fluid comprising a metal-organophosphorus ligand complex catalyst, optionally free organophosphorus ligand, a nonpolar solvent, a polar solvent containing less than about 4 weight percent water, and said one or more products, wherein said process comprises (1) mixing said reaction product fluid to obtain by phase separation a non-polar phase comprising said metal-organophosphorus ligand complex catalyst, optionally free organophosphorus ligand and said nonpolar solvent and a polar phase comprising said one or more products and polar solvent, and (2) recovering said polar phase from said nonpolar phase; wherein said organophosphorus ligand has a partition coefficient between the nonpolar solvent and the polar solvent of greater than about 5, and said one or more products have a partition coefficient between the polar solvent and the nonpolar solvent of greater than about 0.5.

According to another aspect of the present invention, there is provided a process for separating one or more products from a reaction product fluid comprising a metal-organophosphorus ligand complex catalyst, optionally free organophosphorus ligand, a nonpolar solvent and said one or more products, wherein said process comprises (1) mixing said reaction product fluid with a polar solvent containing less than about 4 weight percent water, to obtain by phase separation a non-polar phase comprising such metal-organophosphorus ligand complex catalyst, optionally free organophosphorus ligand and said nonpolar solvent and a polar phase comprising said one or more products and polar solvent, and (2) recovering said polar phase from said nonpolar phase; wherein said organophosphorus ligand has a partition coefficient between the nonpolar solvent and the

polar solvent of greater than about 5, and said one or more products have a partition coefficient between the polar solvent and the nonpolar solvent of greater than about 0.5.

According to still another aspect of the present invention, there is provided a process for producing one or more products comprising: (1) reacting one or more reactants in the presence of a metal-organophosphorus ligand complex catalyst, optionally free organophosphorus ligand, a nonpolar solvent and a polar solvent containing less than about 4 weight percent water, to form a multiphase reaction product fluid; and (2) separating said multiphase reaction product fluid to obtain one phase comprising said one or more reactants, metal-organophosphorus ligand complex catalyst, optionally free organophosphorus ligand and nonpolar solvent and at least one other phase comprising said one or more products and polar solvent; wherein said organophosphorus ligand has a partition coefficient between the nonpolar solvent and the polar solvent of greater than about 5, and said one or more products have a partition coefficient between the polar solvent and the nonpolar solvent of greater than about 0.5.

According to yet another aspect of the present invention, there is provided a process for producing one or more products comprising: (1) reacting one or more reactants in the presence of a metal-organophosphorus ligand complex catalyst, optionally free organophosphorus ligand and a nonpolar solvent to form a reaction product fluid; (2) mixing said reaction product fluid with a polar solvent containing less than about 4 weight percent water, to form a multiphase reaction product fluid; and (3) separating said multiphase reaction product fluid to obtain one phase comprising said one or more reactants, metal-organophosphorus ligand complex catalyst, optionally free

organophosphorus ligand and nonpolar solvent and at least one other phase comprising said one or more products and polar solvent; wherein said organophosphorus ligand has a partition coefficient between the nonpolar solvent and the polar solvent of greater than about 5, and said one or more products have a partition coefficient between the polar solvent and the nonpolar solvent of greater than about 0.5.

Detailed Description

General Processes

The processes of this invention may be asymmetric or non-asymmetric, the preferred processes being non-asymmetric, and may be conducted in any continuous or semi-continuous fashion. The product/catalyst extraction and separation are critical features of this invention and may be conducted as described herein. The processing techniques used in this invention may correspond to any of the known processing techniques heretofore employed in conventional processes. Likewise, the manner or order of addition of the reaction ingredients and catalyst are also not critical and may be accomplished in any conventional fashion. As used herein, the term "reaction product fluid" is contemplated to include, but not limited to, a reaction mixture containing an amount of any one or more of the following: (a) a metal-organophosphorus ligand complex catalyst, (b) free organophosphorus ligand, (c) product(s) formed in the reaction, (d) unreacted reactant(s), and (e) solvent(s).

This invention encompasses the carrying out of known conventional syntheses in a conventional fashion and the carrying out of product/catalyst extractions and separations in accordance with this invention. By the practice of this invention, it is now possible to extract and separate the desired product from the metal-organophosphorus ligand complex catalyst without the need to use vaporization separation and the harsh conditions associated therewith.

Illustrative processes include, for example, hydroformylation, hydroacylation (intramolecular and intermolecular), hydrocyanation, hydroamidation, hydroesterification, aminolysis, alcoholysis, hydrocarbonylation, hydroxycarbonylation, carbonylation, olefin isomerization, transfer hydrogenation and the like. Preferred processes involve the reaction of organic compounds with carbon monoxide, or with carbon monoxide and a third reactant, e.g., hydrogen, or with hydrogen cyanide, in the presence of a catalytic

amount of a metal-organophosphorus ligand complex catalyst. The most preferred processes include hydroformylation, hydrocyanation, hydrocarbonylation, hydroxycarbonylation and carbonylation.

Hydroformylation can be carried out in accordance with conventional procedures known in the art. For example, aldehydes can be prepared by reacting an olefinic compound, carbon monoxide and hydrogen under hydroformylation conditions in the presence of a metal-organophosphorus ligand complex catalyst described herein. Alternatively, hydroxyaldehydes can be prepared by reacting an epoxide, carbon monoxide and hydrogen under hydroformylation conditions in the presence of a metal-organophosphorus ligand complex catalyst described herein. The hydroxyaldehyde can be hydrogenated to a diol, e.g., hydroxypropionaldehyde can be hydrogenated to propanediol. Hydroformylation processes are described more fully hereinbelow.

Intramolecular hydroacylation can be carried out in accordance with conventional procedures known in the art. For example, aldehydes containing an olefinic group 3 to 7 carbons removed can be converted to cyclic ketones under hydroacylation conditions in the presence of a metal-organophosphorus ligand complex catalyst described herein.

Intermolecular hydroacylation can be carried out in accordance with conventional procedures known in the art. For example, ketones can be prepared by reacting an olefin and an aldehyde under hydroacylation conditions in the presence of a metal-organophosphorus ligand complex catalyst described herein.

Hydrocyanation can be carried out in accordance with conventional procedures known in the art. For example, nitrile compounds can be prepared by reacting an olefinic compound and hydrogen cyanide under hydrocyanation conditions in the presence of a metal-organophosphorus ligand complex catalyst described herein. A preferred hydrocyanation process involves reacting a nonconjugated

acyclic aliphatic monoolefin, a monoolefin connected to an ester group, e.g., methyl pent-2-eneoate, or a monoolefin conjugated to a nitrile group, e.g., 3-pentenenitrile, with a source of hydrogen cyanide in the presence of a catalyst precursor composition comprising zero-valent nickel and a bidentate phosphite ligand to produce a terminal organonitrile, e.g., adiponitrile, alkyl 5-cyanovalerate or 3-(perfluoroalkyl)propionitrile. Preferably, the reaction is carried out in the presence of a Lewis acid promoter. Illustrative hydrocyanation processes are disclosed in U.S. Patent No. 5,523,453 and WO 95/14659.

Hydroamidation can be carried out in accordance with conventional procedures known in the art. For example, amides can be prepared by reacting an olefin, carbon monoxide and a primary or secondary amine or ammonia under hydroamidation conditions in the presence of a metal-organophosphorus ligand complex catalyst described herein.

Hydroesterification can be carried out in accordance with conventional procedures known in the art. For example, esters can be prepared by reacting an olefin, carbon monoxide and an alcohol under hydroesterification conditions in the presence of a metal-organophosphorus ligand complex catalyst described herein.

Aminolysis can be carried out in accordance with conventional procedures known in the art. For example, amines can be prepared by reacting an olefin with a primary or secondary amine under aminolysis conditions in the presence of a metal-organophosphorus ligand complex catalyst described herein.

Alcoholysis can be carried out in accordance with conventional procedures known in the art. For example, ethers can be prepared by reacting an olefin with an alcohol under alcoholysis conditions in the presence of a metal-organophosphorus ligand complex catalyst described herein.

Hydrocarbonylation can be carried out in accordance with conventional procedures known in the art. For example, alcohols can be prepared by reacting an olefinic compound, carbon monoxide, hydrogen and a promoter under hydrocarbonylation conditions in the presence of a metal-organophosphorus ligand complex catalyst described herein.

Hydroxycarbonylation can be carried out in accordance with conventional procedures known in the art. For example, acids can be prepared by reacting an olefinic compound, carbon monoxide, water and a promoter under hydroxycarbonylation conditions in the presence of a metal-organophosphorus ligand complex catalyst described herein.

Carbonylation can be carried out in accordance with conventional procedures known in the art. For example, lactones can be prepared by treatment of allylic alcohols with carbon monoxide under carbonylation conditions in the presence of a metal-organophosphorus ligand complex catalyst described herein.

Isomerization can be carried out in accordance with conventional procedures known in the art. For example, allylic alcohols can be isomerized under isomerization conditions to produce aldehydes in the presence of a metal-organophosphorus ligand complex catalyst described herein.

Transfer hydrogenation can be carried out in accordance with conventional procedures known in the art. For example, alcohols can be prepared by reacting a ketone and an alcohol under transfer hydrogenation conditions in the presence of a metal-organophosphorus ligand complex catalyst described herein.

The permissible starting material reactants encompassed by the processes of this invention are, of course, chosen depending on the particular process desired. Such starting materials are well known in the art and can be used in conventional amounts in accordance with conventional methods. Illustrative starting material reactants include, for example, substituted and unsubstituted aldehydes (intramolecular

hydroacylation), olefins (hydroformylation, carbonylation, intermolecular hydroacylation, hydrocyanation, hydroamidation, hydroesterification, aminolysis, alcoholysis), ketones (transfer hydrogenation), epoxides (hydroformylation, hydrocyanation), alcohols (carbonylation) and the like. Illustrative of suitable reactants for effecting the processes of this invention are set out in Kirk-Othmer, Encyclopedia of Chemical Technology, Fourth Edition, 1996.

Illustrative metal-organophosphorus ligand complex catalysts employable in the processes encompassed by this invention as well as methods for their preparation are well known in the art and include those disclosed in the below mentioned patents. In general such catalysts may be preformed or formed in situ as described in such references and consist essentially of metal in complex combination with an organophosphorus ligand. The active species may also contain carbon monoxide and/or hydrogen directly bonded to the metal.

The catalyst useful in the processes includes a metal-organophosphorus ligand complex catalyst which can be optically active or non-optically active. The permissible metals which make up the metal-organophosphorus ligand complexes include Group 8, 9 and 10 metals selected from rhodium (Rh), cobalt (Co), iridium (Ir), ruthenium (Ru), iron (Fe), nickel (Ni), palladium (Pd), platinum (Pt), osmium (Os) and mixtures thereof, with the preferred metals being rhodium, cobalt, iridium and ruthenium, more preferably rhodium, cobalt and ruthenium, especially rhodium. Other permissible metals include Group 11 metals selected from copper (Cu), silver (Ag), gold (Au) and mixtures thereof, and also Group 6 metals selected from chromium (Cr), molybdenum (Mo), tungsten (W) and mixtures thereof. Mixtures of metals from Groups 6, 8, 9, 10 and 11 may also be used in this invention. The permissible organophosphorus ligands which make up the metal-organophosphorus ligand complexes and free organophosphorus ligand include organophosphines, e.g.,

bisphosphines and triorganophosphines, and organophosphites, e.g., mono-, di-, tri- and polyorganophosphites. Other permissible organophosphorus ligands include, for example, organophosphonites, organophosphinites, organophosphorus amides and the like. Mixtures of such ligands may be employed if desired in the metal-organophosphorus ligand complex catalyst and/or free ligand and such mixtures may be the same or different. This invention is not intended to be limited in any manner by the permissible organophosphorus ligands or mixtures thereof. It is to be noted that the successful practice of this invention does not depend and is not predicated on the exact structure of the metal-organophosphorus ligand complex species, which may be present in their mononuclear, dinuclear and/or higher nuclearity forms. Indeed, the exact structure is not known. Although it is not intended herein to be bound to any theory or mechanistic discourse, it appears that the catalytic species may in its simplest form consist essentially of the metal in complex combination with the organophosphorus ligand and carbon monoxide and/or hydrogen when used.

The term "complex" as used herein and in the claims means a coordination compound formed by the union of one or more electronically rich molecules or atoms capable of independent existence with one or more electronically poor molecules or atoms, each of which is also capable of independent existence. For example, the organophosphorus ligands employable herein may possess one or more phosphorus donor atoms, each having one available or unshared pair of electrons which are each capable of forming a coordinate covalent bond independently or possibly in concert (e.g., via chelation) with the metal. Carbon monoxide (which is also properly classified as a ligand) can also be present and complexed with the metal. The ultimate composition of the complex catalyst may also contain an additional ligand, e.g., hydrogen or an anion satisfying the coordination sites or nuclear charge of the metal. Illustrative additional ligands include, for

example, halogen (Cl, Br, I), alkyl, aryl, substituted aryl, acyl, CF_3, C_2F_5, CN, $(R)_2PO$ and $RP(O)(OH)O$ (wherein each R is the same or different and is a substituted or unsubstituted hydrocarbon radical, e.g., the alkyl or aryl), acetate, acetylacetonate, SO_4, PF_4, PF_6, NO_2, NO_3, CH_3O, $CH_2=CHCH_2$, $CH_3CH=CHCH_2$, C_6H_5CN, CH_3CN, NO, NH_3, pyridine, $(C_2H_5)_3N$, mono-olefins, diolefins and triolefins, tetrahydrofuran, and the like. It is of course to be understood that the complex species are preferably free of any additional organic ligand or anion that might poison the catalyst or have an undue adverse effect on catalyst performance. It is preferred in the metal-organophosphorus ligand complex catalyzed processes, e.g., hydroformylation, that the active catalysts be free of halogen and sulfur directly bonded to the metal, although such may not be absolutely necessary. Preferred metal-ligand complex catalysts include rhodium-organophosphine ligand complex catalysts and rhodium-organophosphite ligand complex catalysts.

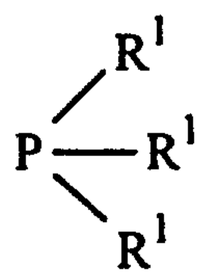
The number of available coordination sites on such metals is well known in the art. Thus the catalytic species may comprise a complex catalyst mixture, in their monomeric, dimeric or higher nuclearity forms, which are preferably characterized by at least one organophosphorus-containing molecule complexed per one molecule of metal, e.g., rhodium. For instance, it is considered that the catalytic species of the preferred catalyst employed in a hydroformylation reaction may be complexed with carbon monoxide and hydrogen in addition to the organophosphorus ligands in view of the carbon monoxide and hydrogen gas employed by the hydroformylation reaction.

The organophosphines and organophosphites that may serve as the ligand of the metal-organophosphorus ligand complex catalyst and/or free ligand of the processes of this invention may be of the achiral (optically inactive) or chiral (optically active) type and are well known in the art. By "free ligand" is meant ligand that is not

complexed with (tied to or bound to) the metal, e.g., metal atom, of the complex catalyst. As noted herein, the processes of this invention and especially the hydroformylation process may be carried out in the presence of free organophosphorus ligand. Achiral organophosphines and organophosphites are preferred.

Among the organophosphines that may serve as the ligand of the metal-organophosphine complex catalyst and/or free organophosphine ligand of the reaction mixture starting materials are triorganophosphines, trialkylphosphines, alkyldiarylphosphines, dialkylarylphosphines, dicycloalkylarylphosphines, cycloalkyldiarylphosphines, triaralkylphosphines, trialkarylphosphines, tricycloalkylphosphines, and triarylphosphines, alkyl and/or aryl bisphosphines and bisphosphine mono oxides, and the like. Of course any of the hydrocarbon radicals of such tertiary non-ionic organophosphines may be substituted if desired, with any suitable substituent that does not unduly adversely affect the desired result of the hydroformylation reaction. The organophosphine ligands employable in the reactions and/or methods for their preparation are known in the art.

Illustrative triorganophosphine ligands may be represented by the formula:



(I)

wherein each R^1 is the same or different and is a substituted or unsubstituted monovalent hydrocarbon radical, e.g., an alkyl or aryl radical. Suitable hydrocarbon radicals may contain from 1 to 24 carbon atoms or greater. Illustrative substituent groups that may be

present on the aryl radicals include, for example, alkyl radicals, alkoxy radicals, silyl radicals such as —$Si(R^2)_3$; amino radicals such as —$N(R^2)_2$; acyl radicals such as —$C(O)R^2$; carboxy radicals such as —$C(O)OR^2$; acyloxy radicals such as —$OC(O)R^2$; amido radicals such as —$C(O)N(R^2)_2$ and —$N(R^2)C(O)R^2$; sulfonyl radicals such as —SO_2R^2; ether radicals such as —OR^2; sulfinyl radicals such as —SOR^2; sulfenyl radicals such as —SR^2 as well as halogen, nitro, cyano, trifluoromethyl and hydroxy radicals, and the like, wherein each R^2 individually represents the same or different substituted or unsubstituted monovalent hydrocarbon radical, with the proviso that in amino substituents such as —$N(R^2)_2$, each R^2 taken together can also represent a divalent bridging group that forms a heterocyclic radical with the nitrogen atom and in amido substituents such as $C(O)N(R^2)_2$ and —$N(R^2)C(O)R^2$ each —R^2 bonded to N can also be hydrogen. Illustrative alkyl radicals include, for example, methyl, ethyl, propyl, butyl and the like. Illustrative aryl radicals include, for example, phenyl, naphthyl, diphenyl, fluorophenyl, difluorophenyl, benzoyloxyphenyl, carboethoxyphenyl, acetylphenyl, ethoxyphenyl, phenoxyphenyl, hydroxyphenyl; carboxyphenyl, trifluoromethylphenyl, methoxyethylphenyl, acetamidophenyl, dimethylcarbamylphenyl, tolyl, xylyl, and the like.

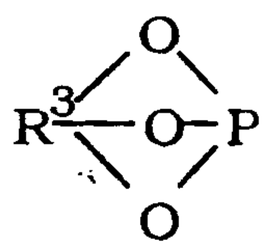
Illustrative specific organophosphines include, for example, triphenylphosphine, tris-p-tolyl phosphine, tris-p-methoxyphenylphosphine, tris-p-fluorophenylphosphine, tris-p-chlorophenylphosphine, tris-dimethylaminophenylphosphine, propyldiphenylphosphine, t-butyldiphenylphosphine, n-butyldiphenylphosphine, n-hexyldiphenylphosphine, cyclohexyldiphenylphosphine, dicyclohexylphenylphosphine, tricyclohexylphosphine, tribenzylphosphine as well as the alkali and alkaline earth metal salts of sulfonated triphenylphosphines, for

example, of (tri-m-sulfophenyl)phosphine and of (m-sulfophenyl)diphenyl-phosphine and the like.

More particularly, illustrative metal-organophosphine complex catalysts and illustrative free organophosphine ligands include, for example, those disclosed in U.S. Patent Nos. 3,527,809; 4,148,830; 4,247,486; 4,283,562; 4,400,548; 4,482,749 and 4,861,918.

Among the organophosphites that may serve as the ligand of the metal-organophosphite complex catalyst and/or free organophosphite ligand of the reaction mixture starting materials are monoorganophosphites, diorganophosphites, triorganophosphites and organopolyphosphites. The organophosphite ligands employable in this invention and/or methods for their preparation are known in the art.

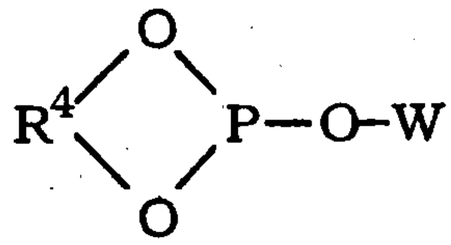
Representative monoorganophosphites may include those having the formula:



(II)

wherein R^3 represents a substituted or unsubstituted trivalent hydrocarbon radical containing from 4 to 40 carbon atoms or greater, such as trivalent acyclic and trivalent cyclic radicals, e.g., trivalent alkylene radicals such as those derived from 1,2,2-trimethylolpropane and the like, or trivalent cycloalkylene radicals such as those derived from 1,3,5-trihydroxycyclohexane, and the like. Such monoorganophosphites may be found described in greater detail, for example, in U.S. Patent No. 4,567,306.

Representative diorganophosphites may include those having the formula:

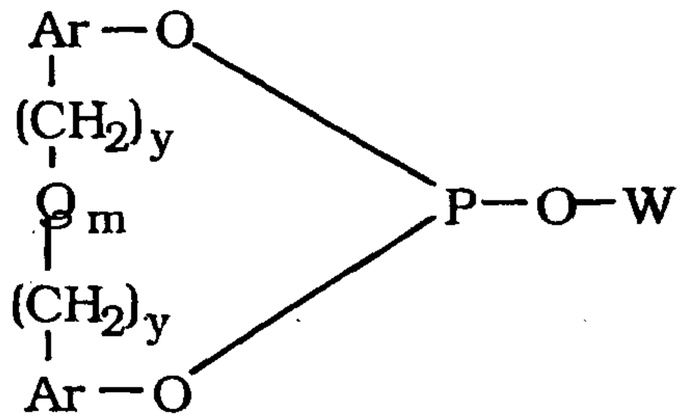


(III)

wherein R^4 represents a substituted or unsubstituted divalent hydrocarbon radical containing from 4 to 40 carbon atoms or greater and W represents a substituted or unsubstituted monovalent hydrocarbon radical containing from 1 to 18 carbon atoms or greater.

Representative substituted and unsubstituted monovalent hydrocarbon radicals represented by W in the above formula (III) include alkyl and aryl radicals, while representative substituted and unsubstituted divalent hydrocarbon radicals represented by R^4 include divalent acyclic radicals and divalent aromatic radicals. Illustrative divalent acyclic radicals include, for example, alkylene, alkylene-oxy-alkylene, alkylene-NX-alkylene wherein X is hydrogen or a substituted or unsubstituted monovalent hydrocarbon radical, alkylene-S-alkylene, and cycloalkylene radicals, and the like. The more preferred divalent acyclic radicals are the divalent alkylene radicals such as disclosed more fully, for example, in U.S. Patent Nos. 3,415,906 and 4,567,302 and the like. Illustrative divalent aromatic radicals include, for example, arylene, bisarylene, arylene-alkylene, arylene-alkylene-arylene, arylene-oxy-arylene, arylene-NX-arylene wherein X is as defined above, arylene-S-arylene, and arylene-S-alkylene, and the like. More preferably R^4 is a divalent aromatic radical such as disclosed more fully, for example, in U.S. Patent Nos. 4,599,206 and 4,717,775.

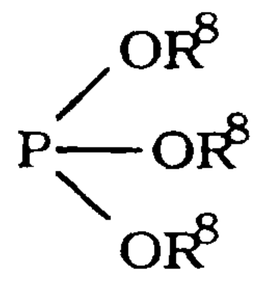
Representative of a more preferred class of diorganophosphites are those of the formula:



(IV)

wherein W is as defined above, each Ar is the same or different and represents a substituted or unsubstituted aryl radical, each y is the same or different and is a value of 0 or 1, Q represents a divalent bridging group selected from $-C(R^5)_2-$, -O-, -S-, $-NR^6-$, $Si(R^7)_2-$ and -CO-, wherein each R^5 is the same or different and represents hydrogen, alkyl radicals having from 1 to 12 carbon atoms, phenyl, tolyl, and anisyl, R^6 represents hydrogen or a methyl radical, each R^7 is the same or different and represents hydrogen or a methyl radical, and m is a value of 0 or 1. Such diorganophosphites are described in greater detail, for example, in U.S. Patent Nos. 4,599,206, 4,717,775 and 4,835,299.

Representative triorganophosphites may include those having the formula:

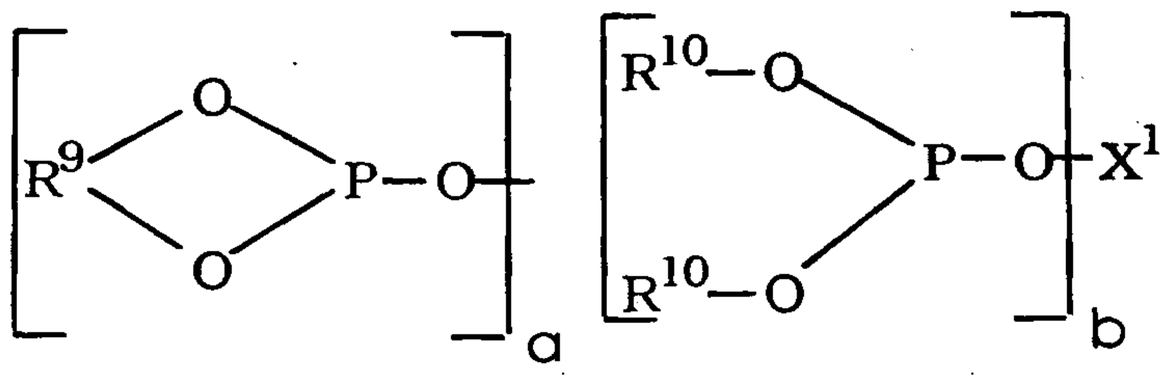


(V)

wherein each R^8 is the same or different and is a substituted or unsubstituted monovalent hydrocarbon radical e.g., an alkyl, cycloalkyl, aryl, alkaryl and aralkyl radicals which may contain from 1 to 24 carbon atoms. Suitable hydrocarbon radicals may contain from 1 to 24 carbon atoms or greater and may include those described above for R^1 in formula (I). Illustrative triorganophosphites include, for example, trialkyl phosphites, dialkylaryl phosphites, alkyldiaryl phosphites, triaryl phosphites, and the like, such as, for example, trimethyl phosphite, triethyl phosphite, butyldiethyl phosphite, tri-n-propyl phosphite, tri-n-butyl phosphite, tri-2-ethylhexyl phosphite, tri-n-octyl phosphite, tri-n-dodecyl phosphite, dimethylphenyl phosphite, diethylphenyl phosphite, methyldiphenyl phosphite, ethyldiphenyl phosphite, triphenyl phosphite, trinaphthyl phosphite, bis(3,6,8-tri-t-butyl-2-naphthyl)methylphosphite, bis(3,6,8-tri-t-butyl-2-naphthyl)cyclohexylphosphite, tris(3,6-di-t-butyl-2-naphthyl)phosphite, bis(3,6,8-tri-t-butyl-2-naphthyl)(4-biphenyl)phosphite, bis(3,6,8-tri-t-butyl-2-naphthyl)phenylphosphite, bis(3,6,8-tri-t-butyl-2-naphthyl)(4-benzoylphenyl)phosphite, bis(3,6,8-tri-t-butyl-2-naphthyl)(4-sulfonylphenyl)phosphite, and the like. The most preferred triorganophosphite is triphenylphosphite. Such triorganophosphites are described in greater detail, for example, in U.S. Patent Nos. 3,527,809 and 5,277,532,

Representative organopolyphosphites contain two or more tertiary (trivalent) phosphorus atoms and may include those having the formula:

D-17782



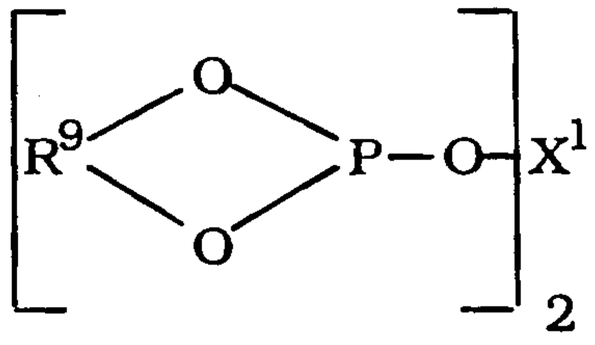
(VI)

wherein X^1 represents a substituted or unsubstituted n-valent hydrocarbon bridging radical containing from 2 to 40 carbon atoms, each R^9 is the same or different and is a divalent hydrocarbon radical containing from 4 to 40 carbon atoms, each R^{10} is the same or different and is a substituted or unsubstituted monovalent hydrocarbon radical containing from 1 to 24 carbon atoms, a and b can be the same or different and each have a value of 0 to 6, with the proviso that the sum of a + b is 2 to 6 and n equals a + b. Of course it is to be understood that when a has a value of 2 or more, each R^9 radical may be the same or different, and when b has a value of 1 or more, each R^{10} radical may also be the same or different.

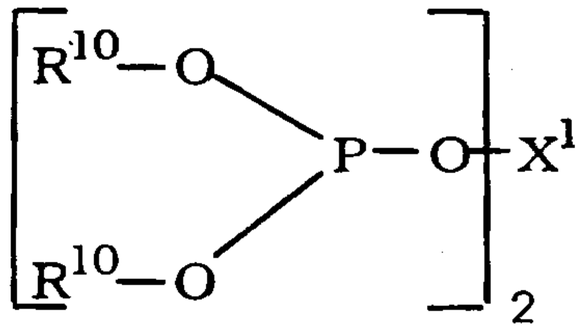
Representative n-valent (preferably divalent) hydrocarbon bridging radicals represented by X^1, as well as representative divalent hydrocarbon radicals represented by R^9 above, include both acyclic radicals and aromatic radicals, such as alkylene, alkylene-Q_m-alkylene, cycloalkylene, arylene, bisarylene, arylene-alkylene, and arylene-$(CH_2)_y$-Q_m-$(CH_2)_y$-arylene radicals, and the like, wherein Q, m and y are as defined above for formula (IV). The more preferred acyclic radicals represented by X^1 and R^9 above are divalent alkylene radicals, while the more preferred aromatic radicals represented by X^1 and R^9 above are divalent arylene and bisarylene radicals, such as disclosed more fully, for example, in U.S. Patent Nos. 4,769,498; 4,774,361: 4,885,401; 5,179,055; 5,113,022; 5,202,297; 5,235,113; 5,264,616 and 5,364,950, and European Patent Application Publication No. 662,468, and the like.

Representative monovalent hydrocarbon radicals represented by each R^{10} radical above include alkyl and aromatic radicals.

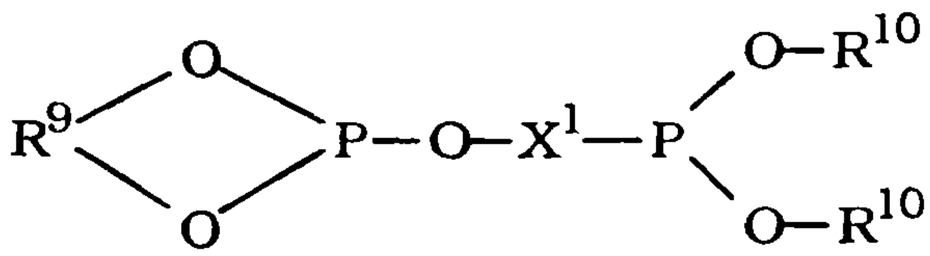
Illustrative preferred organopolyphosphites may include bisphosphites such as those of formulas (VII) to (IX) below:



(VII)



(VIII)

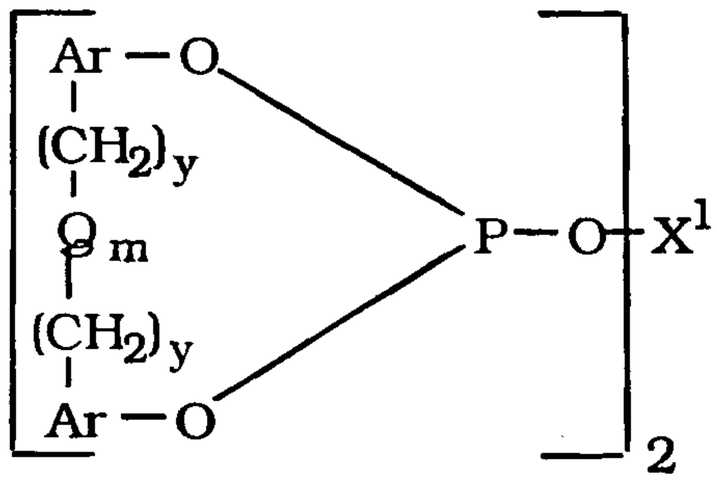


(IX)

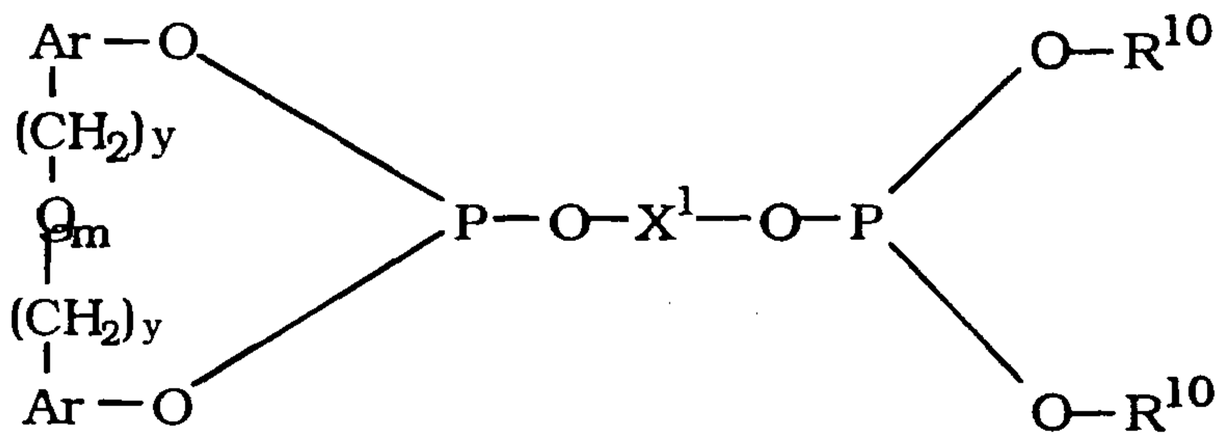
wherein each R^9, R^{10} and X^1 of formulas (VII) to (IX) are the same as defined above for formula (VI). Preferably, each R^9 and X^1 represents a divalent hydrocarbon radical selected from alkylene, arylene, arylene-alkylene-arylene, and bisarylene, while each R^{10} represents a monovalent hydrocarbon radical selected from alkyl and aryl radicals.

Organophosphite ligands of such Formulas (VI) to (IX) may be found disclosed, for example, in U.S. Patent Nos. 4,668,651; 4,748,261; 4,769,498; 4,774,361; 4,885,401; 5,113,022; 5,179,055; 5,202,297; 5,235,113; 5,254,741; 5,264,616; 5,312,996; 5,364,950; and 5,391,801.

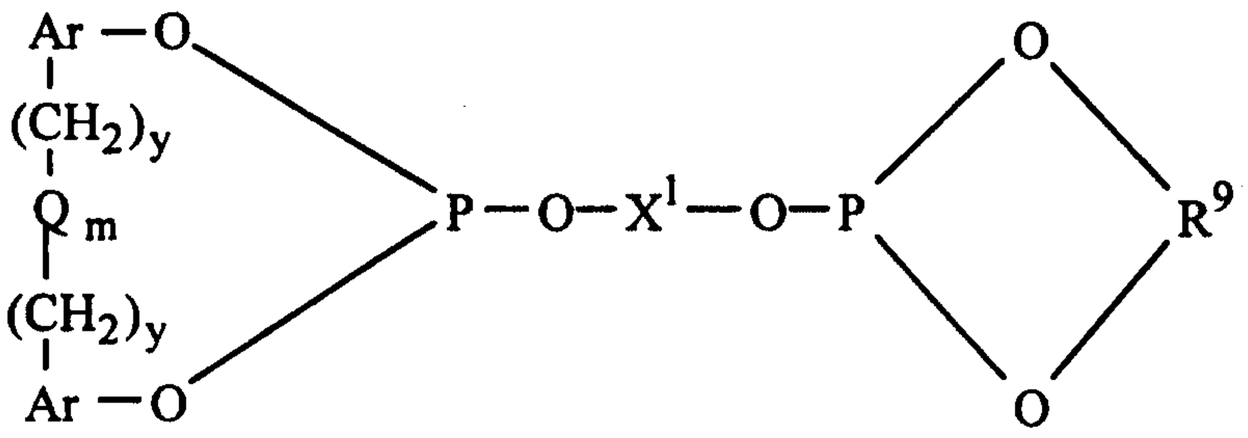
Representative of more preferred classes of organobisphosphites are those of the following formulas (X) to (XII):



(X)



(XI)



(XII)

wherein Ar, Q , R^9, R^{10}, X^1, m and y are as defined above. Most preferably X^1 represents a divalent aryl-$(CH_2)_y$-$(Q)_m$-$(CH_2)_y$-aryl radical wherein each y individually has a value of 0 or 1; m has a value of 0 or 1 and Q is -O-, -S- or-$C(R^5)_2$- wherein each R^5 is the same or different and represents a hydrogen or methyl radical. More preferably each alkyl radical of the above defined R^{10} groups may contain from 1 to 24 carbon atoms and each aryl radical of the above-defined Ar, X^1, R^9 and R^{10} groups of the above formulas (VI) to (XII) may contain from 6 to 18 carbon atoms and said radicals may be the same or different, while the preferred alkylene radicals of X^1 may contain from 2 to 18 carbon atoms and the preferred alkylene radicals of R^9 may contain from 5 to 18 carbon atoms. In addition, preferably the divalent Ar radicals and divalent aryl radicals of X^1 of the above formulas are phenylene radicals in which the bridging group represented by –$(CH_2)_y$–$(Q)_m$–$(CH_2)_y$– is bonded to said phenylene radicals in positions that are ortho to the oxygen atoms of the formulas that connect the phenylene radicals to their phosphorus atom of the formulae. It is also preferred that any substituent radical when present on such phenylene radicals be bonded in the para and/or ortho position of the phenylene radicals in relation to the oxygen atom that bonds the given substituted phenylene radical to its phosphorus atom.

Of course any of the R^3, R^4, R^8, R^9, R^{10}, X^1, X^2, W, Q and Ar radicals of such organophosphites of formulas (II) to (XII) above

may be substituted if desired, with any suitable substituent containing from 1 to 30 carbon atoms that does not unduly adversely affect the desired result of the hydroformylation reaction. Substituents that may be on said radicals in addition of course to corresponding hydrocarbon radicals such as alkyl, aryl, aralkyl, alkaryl and cyclohexyl substituents, may include for example silyl radicals such as $-Si(R^{12})_3$; amino radicals such as $-N(R^{12})_2$; phosphine radicals such as -aryl-$P(R^{12})_2$; acyl radicals such as $-C(O)R^{12}$; acyloxy radicals such as $-OC(O)R^{12}$; amido radicals such as $-CON(R^{12})_2$ and $-N(R^{12})COR^{12}$; sulfonyl radicals such as $-SO_2R^{12}$; alkoxy radicals such as $-OR^{12}$; sulfinyl radicals such as $-SOR^{12}$; sulfenyl radicals such as $-SR^{12}$; phosphonyl radicals such as $-P(O)(R^{12})_2$; as well as, halogen, nitro, cyano, trifluoromethyl, hydroxy radicals, and the like, wherein each R^{12} radical is the same or different and represents a monovalent hydrocarbon radical having from 1 to 18 carbon atoms (e.g., alkyl, aryl, aralkyl, alkaryl and cyclohexyl radicals), with the proviso that in amino substituents such as $-N(R^{12})_2$ each R^{12} taken together can also represent a divalent bridging group that forms a heterocyclic radical with the nitrogen atom, and in amido substituents such as $-C(O)N(R^{12})_2$ and $-N(R^{12})COR^{12}$ each R^{12} bonded to N can also be hydrogen. Of course it is to be understood that any of the substituted or unsubstituted hydrocarbon radicals groups that make up a particular given organophosphite may be the same or different.

More specifically illustrative substituents include primary, secondary and tertiary alkyl radicals such as methyl, ethyl, n-propyl, isopropyl, butyl, sec-butyl, t-butyl, neo-pentyl, n-hexyl, amyl, sec-amyl, t-amyl, iso-octyl, decyl, octadecyl, and the like; aryl radicals such as phenyl, naphthyl and the like; aralkyl radicals such as benzyl, phenylethyl, triphenylmethyl, and the like; alkaryl radicals such as tolyl, xylyl, and the like; alicyclic radicals such as cyclopentyl, cyclohexyl, 1-methylcyclohexyl, cyclooctyl, cyclohexylethyl, and the

like; alkoxy radicals such as methoxy, ethoxy, propoxy, t-butoxy, -$OCH_2CH_2OCH_3$, -$(OCH_2CH_2)_2OCH_3$, -$(OCH_2CH_2)_3OCH_3$, and the like; aryloxy radicals such as phenoxy and the like; as well as silyl radicals such as -$Si(CH_3)_3$, -$Si(OCH_3)_3$, -$Si(C_3H_7)_3$, and the like; amino radicals such as -NH_2, -$N(CH_3)_2$, -$NHCH_3$, -$NH(C_2H_5)$, and the like; arylphosphine radicals such as -$P(C_6H_5)_2$, and the like; acyl radicals such as -$C(O)CH_3$, -$C(O)C_2H_5$, -$C(O)C_6H_5$, and the like; carbonyloxy radicals such as -$C(O)OCH_3$ and the like; oxycarbonyl radicals such as -$O(CO)C_6H_5$, and the like; amido radicals such as -$CONH_2$, -$CON(CH_3)_2$, -$NHC(O)CH_3$, and the like; sulfonyl radicals such as -$S(O)_2C_2H_5$ and the like; sulfinyl radicals such as -$S(O)CH_3$ and the like; sulfenyl radicals such as -SCH_3, -SC_2H_5, -SC_6H_5, and the like; phosphonyl radicals such as -$P(O)(C_6H_5)_2$, -$P(O)(CH_3)_2$, -$P(O)(C_2H_5)_2$, -$P(O)(C_3H_7)_2$, -$P(O)(C_4H_9)_2$, -$P(O)(C_6H_{13})_2$, -$P(O)CH_3(C_6H_5)$, -$P(O)(H)(C_6H_5)$, and the like.

Specific illustrative examples of organophosphorus ligands are described in copending U.S. Patent Application Serial No. 08/757,743 filed November 26, 1996, and issued on March 19, 1998, as US Patent No. 5,728,893.

The metal-organophosphorus ligand complex catalysts are preferably in homogeneous form. For instance, preformed rhodium hydrido-carbonyl-organophosphorus ligand catalysts may be prepared and introduced into the reaction mixture of a particular process. More preferably, the metal-organophosphorus ligand complex catalysts can be derived from a rhodium catalyst precursor which may be introduced into the reaction medium for in situ formation of the active catalyst. For example, rhodium catalyst precursors such as rhodium dicarbonyl acetylacetonate, Rh_2O_3, $Rh_4(CO)_{12}$, $Rh_6(CO)_{16}$, $Rh(NO_3)_3$ and the like may be introduced into the reaction mixture along with the organophosphorus ligand for the in situ formation of the active catalyst.

As noted above, the organophosphorus ligands can be employed as both the ligand of the metal-organophosphorus ligand complex catalyst, as well as, the free organophosphorus ligand that can be present in the reaction medium of the processes of this invention. In addition, it is to be understood that while the organophosphorus ligand of the metal-organophosphorus ligand complex catalyst and any excess free organophosphorus ligand preferably present in a given process of this invention are normally the same type of ligand, different types of organophosphorus ligands, as well as, mixtures of two or more different organophosphorus ligands may be employed for each purpose in any given process, if desired.

The amount of metal-organophosphorus ligand complex catalyst present in the reaction medium of a given process of this invention need only be that minimum amount necessary to provide the given metal concentration desired to be employed and which will furnish the basis for at least that catalytic amount of metal necessary to catalyze the particular process desired. In general, metal concentrations in the range of from about 1 part per million to about 10,000 parts per million, calculated as free metal, and ligand to metal mole ratios in the catalyst solution ranging from about 1:1 or less to about 200:1 or greater, should be sufficient for most processes.

As noted above, in addition to the metal-organophosphorus ligand complex catalysts, the processes of this invention and especially the hydroformylation process can be carried out in the presence of free organophosphorus ligand. While the processes of this invention may be carried out in any excess amount of free organophosphorus ligand desired, the employment of free organophosphorus ligand may not be absolutely necessary. Accordingly, in general, amounts of ligand of from about 1.1 or less to about 200, or higher if desired, moles per mole of metal (e.g., rhodium) present in the reaction medium should be suitable for most purposes, particularly with regard to rhodium catalyzed hydroformylation; said

amounts of ligand employed being the sum of both the amount of ligand that is bound (complexed) to the metal present and the amount of free (non-complexed) ligand present. Of course, if desired, make-up ligand can be supplied to the reaction medium of the process, at any time and in any suitable manner, to maintain a predetermined level of free ligand in the reaction medium.

The permissible reaction conditions employable in the processes of this invention are, of course, chosen depending on the particular syntheses desired. Such process conditions are well known in the art. All of the processes of this invention can be carried out in accordance with conventional procedures known in the art. Illustrative reaction conditions for conducting the processes of this invention are described, for example, in Kirk-Othmer, Encyclopedia of Chemical Technology, Fourth Edition, 1996. Depending on the particular process, operating temperatures may range from about -80°C or less to about 500°C or greater and operating pressures can range from about 1 psig or less to about 10,000 psig or greater.

The processes of this invention are conducted for a period of time sufficient to produce the desired products. The exact reaction time employed is dependent, in part, upon factors such as temperature, pressure, nature and proportion of starting materials, and the like. The reaction time will normally be within the range of from about one-half to about 200 hours or more, and preferably from less than about one to about 10 hours.

The processes of this invention are useful for preparing substituted and unsubstituted optically active and non-optically active compounds. Illustrative compounds prepared by the processes of this invention include, for example, substituted and unsubstituted alcohols or phenols; amines; amides; ethers or epoxides; esters; ketones; aldehydes; and nitriles. Illustrative of suitable optically active and non-optically active compounds which can be prepared by the processes

of this invention (including starting material compounds as described hereinabove) include those permissible compounds which are described in Kirk-Othmer, Encyclopedia of Chemical Technology, Fourth Edition, 1996, and The Merck Index, An Encyclopedia of Chemicals, Drugs and Biologicals, Eleventh Edition, 1989.

In accordance with one embodiment of this invention, one or more reactants are reacted in the presence of a metal-organophosphorus ligand complex catalyst, optionally free organophosphorus ligand, a nonpolar solvent and a polar solvent to form a multiphase reaction product fluid and this fluid is then separated to obtain one phase comprising the one or more reactants, metal-organophosphorus ligand complex catalyst, optionally free organophosphorus ligand and nonpolar solvent and at least one other phase comprising one or more products and polar solvent. During the reaction, the reaction product fluid comprising one or more reactants, a metal-organophosphorus ligand complex catalyst, optionally free organophosphorus ligand, one or more products and a nonpolar solvent is in intimate contact with the polar solvent such that the one or more products are extracted selectively into the polar solvent. This extraction is followed by phase separation in which a layer of the extraction fluid, i.e., polar solvent and one or more products, is separated from a layer of the reaction product fluid.

In accordance with another embodiment of this invention, one or more reactants are reacted in the presence of a metal-organophosphorus ligand complex catalyst, optionally free organophosphorus ligand and a nonpolar solvent to form a reaction product fluid, the reaction product fluid is then contacted with a polar solvent to form a multiphase reaction product fluid, and this fluid is then separated to obtain one phase comprising the one or more reactants, metal-organophosphorus ligand complex catalyst, optionally

free organophosphorus ligand and nonpolar solvent and at least one other phase comprising the one or more products and polar solvent. After the reaction, the reaction product fluid comprising one or more reactants, a metal-organophosphorus ligand complex catalyst, optionally free organophosphorus ligand, one or more products and a nonpolar solvent is intimately contacted with the polar solvent such that the one or more products are extracted selectively into the polar solvent. This extraction is followed by phase separation in which a layer of the extraction fluid, i.e., polar solvent and one or more products, is separated from a layer of the reaction product fluid.

As indicated above, the processes of this invention are conducted in the presence of a nonpolar solvent and a polar solvent, or in the presence of a nonpolar solvent followed by mixing with a polar solvent. Depending on the particular catalyst and reactants employed, suitable nonpolar solvents include, for example, alkanes, cycloalkanes, alkenes, aldehydes, ketones, ethers, esters, amines, aromatics, silanes, silicones, carbon dioxide, and the like. Examples of unsuitable nonpolar solvents include fluorocarbons and fluorinated hydrocarbons. These are undesirable due to their high cost, risk of environmental pollution, and the potential of forming multiphases.

Mixtures of one or more different nonpolar solvents may be employed if desired. The amount of nonpolar solvent employed is not critical to the subject invention and need only be that amount sufficient to provide the reaction medium with the particular metal concentration desired for a given process. In general, the amount of nonpolar solvent employed may range from about 5 percent by weight up to about 99 percent by weight or more based on the total weight of the reaction mixture.

Illustrative nonpolar solvents useful in this invention include, for example, propane, 2,2-dimethylpropane, butane, 2,2-dimethylbutane, pentane, isopropyl ether, hexane, triethylamine, heptane, octane, nonane, decane, isobutyl isobutyrate, tributylamine,

undecane, 2,2,4-trimethylpentyl acetate, isobutyl heptyl ketone, diisobutyl ketone, cyclopentane, cyclohexane, isobutylbenzene, n-nonylbenzene, n-octylbenzene, n-butylbenzene, p-xylene, ethylbenzene, 1,3,5-trimethylbenzene, m-xylene, toluene, o-xylene, decene, docenene, tetradecene, and heptadecanal. The solubility parameters of illustrative nonpolar solvents are given in the Table below.

Table - Solubility Parameters of Illustrative Non-Polar Solvents

Non-Polar Solvent	$\delta_{Solvent}$ $(cal/cm^3)^{1/2}$	$\delta_{Solvent}$ $(kJ/m^3)^{1/2}$
Propane	5.76	373
2,2-Dimethylpropane	6.10	395
Butane	6.58	426
2,2-Dimethylbutane	6.69	433
Pentane	7.02	454
Isopropyl Ether	7.06	457
Hexane	7.27	470
Triethylamine	7.42	480
Heptane	7.50	485
Octane	7.54	488
Nonane	7.64	494
Decane	7.72	499
Isobutyl Isobutyrate	7.74	501
Tributylamine	7.76	502
Undecane	7.80	505
2,2,4-Trimethylpentyl Acetate	7.93	513
Isobutyl Heptyl Ketone	7.95	514
Diisobutyl Ketone	8.06	521
Cyclopentane	8.08	523
Cyclohexane	8.19	530
n-Nonylbenzene	8.49	549
n-Octylbenzene	8.56	554
n-Butylbenzene	8.57	554
p-Xylene	8.83	571
Ethylbenzene	8.84	572
1,3,5-Trimethylbenzene	8.84	572

m-Xylene	8.88	574
Toluene	8.93	578
o-Xylene	9.06	586

The desired products of this invention can be selectively recovered by extraction and phase separation in a polar solvent. As indicated above, the polar solvent can be present with the nonpolar solvent during the reaction or the reaction product fluid can be contacted with a polar solvent after the reaction. The desired reaction product is preferably extracted from the reaction product fluid through the use of an appropriate polar solvent such that any extraction of the one or more reactants, metal-organophosphorus ligand complex catalyst, and optionally free organophosphorus ligand from the reaction product fluid is minimized or eliminated. The polar solvent may contain up to about 8 weight percent water, preferably less than about 6 weight percent water, and most preferably less than about 4 weight percent water. The presence of a small amount of water may improve extraction efficiency and provide stabilization of certain products. A large amount of water is undesirable because it may lead to the formation of multiphases, hydrolysis of certain phosphorous containing ligands, and decreased solubility of the ligand and/or catalyst in the polar solvent. It is to be understood that the processes of this invention are considered to be essentially "non-aqueous" processes, which is to say, any water present in the reaction mediums is not present in an amount sufficient to cause either the particular reaction or said medium to be considered as encompassing a separate aqueous or water phase or layer in addition to the organic phases. Depending on the particular desired products, suitable polar solvents include, for example, nitriles, lactones, pyrrolidones, formamides, sulfoxides and the like. Examples of unsuitable polar solvents include simple alcohols, diols, triols, polyols, primary amines, secondary amines, and the like, since they can react with aldehyde products to

give undesirable by-products which lead to lower reaction efficiencies and could complicate phase separations. For purposes of this invention, the polar solvent is other than a combination of a primary alkanol and water.

Mixtures of one or more different polar solvents may be employed if desired. The Hildebrand solubility parameter for the polar solvent or mixtures of one or more different polar solvents should be less than about 13.5 $(cal/cm^3)^{1/2}$ or 873 $(kJ/m^3)^{1/2}$, preferably less than about 13.0 $(cal/cm^3)^{1/2}$ or 841 $(kJ/m^3)^{1/2}$, and more preferably less than about 12.5 $(cal/cm^3)^{1/2}$ or 809 $(kJ/m^3)^{1/2}$. The amount of polar solvent employed is not critical to the subject invention and need only be that amount sufficient to extract the one or more products from the reaction product fluid for any given process. In general, the amount of polar solvent employed may range from about 5 percent by weight up to about 50 percent by weight or more based on the total weight of the reaction product fluid.

Illustrative polar solvents useful in this invention include, for example, propionitrile, 1,3-dioxolane, 3-methoxypropionitrile, N-methylpyrrolidone, N,N-dimethylformamide, 2-methyl-2-oxazoline, adiponitrile, acetonitrile, epsilon caprolactone, glutaronitrile, 3-methyl-2-oxazolidinone, dimethyl sulfoxide and sulfolane. The solubility parameters of illustrative polar solvents are given in the Table below.

Table - Solubility Parameters of Illustrative Polar Solvents

Polar Solvent	$\delta_{Solvent}$ $(cal/cm^3)^{1/2}$	$\delta_{Solvent}$ $(kJ/m^3)^{1/2}$
Propionitrile	10.73	694
1,3-Dioxolane	11.33	733
3-Methoxypropionitrile	11.37	735
N-Methylpyrrolidone	11.57	748

N,N-Dimethylformamide	11.76	761
2-Methyl-2-Oxazoline	12.00	776
Adiponitrile	12.05	779
Acetonitrile	12.21	790
E-Caprolactone	12.66	819
Sulfolane	12.80	828
Glutaronitrile	13.10	847
Dimethyl Sulfoxide	13.10	847
3-Methyl-2-Oxazolidinone	13.33	862

Extraction to obtain one phase comprising the one or more reactants, metal-organophosphorus ligand complex catalyst. optionally free organophosphorus ligand and nonpolar solvent and at least one other phase comprising one or more products and polar solvent is an equilibrium process. The relative volumes of the polar solvent (or extraction solution) and the nonpolar solvent or reaction product fluid in this extraction operation are determined in part by the solubility of the one or more reactants, metal-organophosphorus ligand complex catalyst, optionally free organophosphorus ligand and one or more products in the solvents used, and the amount of desired product to be extracted. For example, when the desired product is extracted, if the desired product to be extracted shows high solubility in the polar solvent and is present at a relatively low concentration in the reaction product fluid, it is possible to extract the desired product by using the polar solvent in a relatively small volume ratio to the reaction product fluid.

Further, as the concentration of the desired product becomes high, it is usually required to increase the ratio of the polar solvent to the reaction product fluid for extracting the desired product from the reaction product fluid. When the desired product shows relatively low solubility in the polar solvent, the relative volume of the polar solvent or extraction solution will have to be increased. Generally, the volume ratio of the polar solvent or extraction solution

to the reaction product fluid may be changed within a range of from about 10:1 to about 1:10.

With respect to the extraction temperature, there is no merit in employing a temperature higher than the reaction temperature of the particular process, and desirable results can be obtained by employing an extraction temperature lower than the process reaction temperature. Depending on the particular process, extraction temperatures may range from about -80°C or less to about 200°C or greater.

The time for mixing the reaction product fluid with the polar solvent, i.e. the time before the phase separation, depends on the rate until the two-phases reach the equilibrium condition. Generally, such a time maybe varied from within one minute or less to a long period of one hour or more.

The extraction process of this invention is in part an equilibrium process of an organophosphorus ligand dissolved in two separate liquid phases. The efficiency of this extraction process can be measured by a partition coefficient Kp of the organophosphorus ligand which is defined as follows:

$$Kp = \frac{\text{Concentration of organophosphorus ligand in the nonpolar solvent after extraction}}{\text{Concentration of organophosphorus ligand in the polar solvent after extraction}}$$

When the one or more desired products are partitioned between the reaction product fluid and the polar solvent by the extraction process of this invention, the Kp value of the organophosphorus ligand can be maintained at a level greater than about 5, preferably greater than about 7.5, and more preferably greater than about 10, depending on the efficiency of the extraction process. If this Kp value is high, the extraction efficiency will be high.

The extraction process of this invention is also in part an equilibrium process of one or more products dissolved in two separate liquid phases. The efficiency of this extraction process can be measured by a partition coefficient Kp of the one or more products which is defined as follows:

$$Kp = \frac{\text{Concentration of products in the polar solvent after extraction}}{\text{Concentration of products in the nonpolar solvent after extraction}}$$

When the one or more desired products are partitioned between the reaction product fluid and the polar solvent by the extraction process of this invention, the Kp value of the products can be maintained at a level greater than about 0.5, preferably greater than about 0.75, and more preferably greater than about 1, depending on the efficiency of the extraction process. If this Kp value is high, the extraction efficiency will be high.

The extraction process of this invention may be conducted in one or more stages. The exact number of extraction stages will be governed by the best compromise between capital costs and achieving high extraction efficiency and ease of operability, as well as the stability of the starting materials and the desired reaction product to the extraction conditions. Also, the extraction process of this invention may be conducted in a batch or continuous fashion. When conducted continuously, the extraction may be conducted in a current or countercurrent manner or fractional extraction may be used.

Illustrative types of extractors that may be employed in this invention include, for example, columns, centrifuges, mixer-settlers, and miscellaneous devices. A description of these devices can be found in the Handbook of Solvent Extraction, ISBN 0-89464-546-3, Krieger Publishing Company, 1991.

As used in this invention, the various types of extractors may be combined in any combination to effect the desired extraction.

Following the extraction, the desired products of this invention may be recovered by phase separation in which a layer of the extraction fluid, i.e., polar solvent and one or more products, is separated from a layer of the reaction product fluid. The phase separation techniques may correspond to those techniques heretofore employed in conventional processes.

From a free energy standpoint, to attain dissolution or miscibility of a phosphorous containing ligand in a particular solvent, the enthalpy of mixing should be as small as possible. The enthalpy of mixing (ΔH_m) can be approximated by the Hildebrand equation (1)

$$\Delta H_m = \Phi_S \Phi_L V(\delta_{Solvent} - \delta_{Ligand})^2 \qquad (1)$$

using the solubility parameters of the solvent ($\delta_{Solvent}$) and ligand (δ_{Ligand}), where V is the molar volume of the mixture, and Φ_S and Φ_L are the volume fractions of the solvent and ligand, respectively. Based on equation (1), the ideal solvent for a ligand would have the same solubility parameter as the ligand itself, so that $\Delta H_m = 0$. However, for each ligand there is a characteristic range originating from its solubility parameter which encloses all liquids that are solvents for the ligand. In general, a solvent or a solvent blend having a solubility parameter that is within two units of the solubility parameter of the ligand will dissolve the ligand; however, relatively large deviations from this value can sometimes occur, especially if there are strong hydrogen bonding interactions. Therefore, equation (2)

$$\delta_{Solvent} - \delta_{Ligand} < 2.0 \ (cal/cm^3)^{1/2} \qquad (2)$$

can be used semi-quantitatively to determine whether a liquid is a good solvent for a given ligand. In equation (2), $\delta_{Solvent}$ and δ_{Ligand} represent the solubility parameters of the solvent and ligand respectively.

For purposes of this invention, the solubility parameters for solvents can be calculated from equation (3)

$$\delta_{Solvent} = (\Delta H_V - RT)d / MW \qquad (3)$$

in which ΔH_v is the heat of vaporization, R is a gas constant, T is temperature in degrees absolute, d is the density of the solvent, and MW is molecular weight of the solvent. The solubility parameters for a wide variety of solvents have been reported by K. L. Hoy, "New Values of the Solubility Parameters from Vapor Pressure Data," Journal of Paint Technology, 42, (1970), 76.

The heat of vaporization for phosphorous containing compounds cannot be easily measured since many of these compounds decompose at higher temperatures. Furthermore, since many phosphorous containing compounds are solids at room temperature, measurements of density are not convenient. The solubility parameters, in units of $(cal/cm^3)^{1/2}$, for phosphorus containing ligands can be calculated using equation (4)

$$\delta_{Ligand} = (\sum F_T + 135.1) / (0.01211 + \sum N_i V_{1i})1000 \qquad (4)$$

from group contribution theory as developed by (1) K. L. Hoy, "New Values of the Solubility Parameters from Vapor Pressure Data," Journal of Paint Technology, 42, (1970), 76, and (2) L. Constantinou, R. Gani, J. P. O'Connell, "Estimation of the Acentric Factor and the Liquid Molar Volume at 298 K Using a New Group Contribution Method," Fluid Phase Equilibria, 103, (1995), 11. In equation (4), $\sum F_T$ is the sum of all the group molar attraction constants, and $\sum N_i V_{1i}$ is

the sum of all the first order liquid molar volume constants V_{1i} , which occur N_i times. These methods have been expanded to include the group molar attraction constant of 79.4 $(cal/cm^3)^{1/2}$/mole and first order liquid molar volume constant of 0.0124 m^3/kmol for (>P-) derived from triphenylphosphine data found in T. E. Daubret, R. P. Danner, H. M. Sibul, and C. C. Stebbins, "DIPPR Data Compilation of Pure Compound Properties," Project 801, Sponsor Release, July 1995, Design Institute for Physical Property Data, AIChE, New York, NY.

The processes of this invention can be conducted in a batch or continuous fashion, with recycle of unconsumed starting materials if required. The reaction can be conducted in a plurality of reaction zones, in series or in parallel or it may be conducted batchwise or continuously in an elongated tubular zone or series of such zones. For example, a backmixed reactor may be employed in series with a multistaged reactor with the backmixed reactor being first. The materials of construction employed should be inert to the starting materials during the reaction and the fabrication of the equipment should be able to withstand the reaction temperatures and pressures. Means to introduce and/or adjust the quantity of starting materials or ingredients introduced batchwise or continuously into the reaction zone during the course of the reaction can be conveniently utilized in the processes especially to maintain the desired molar ratio of the starting materials. The reaction steps may be effected by the incremental addition of one of the starting materials to the other. Also, the reaction steps can be combined by the joint addition of the starting materials. When complete conversion is not desired or not obtainable, the starting materials can be separated from the product by phase separation. and the starting materials then recycled back into the reaction zone.

The processes may be conducted in either glass lined, stainless steel or similar type reaction equipment. The reaction zone may be fitted with one or more internal and/or external heat

exchanger(s) in order to control undue temperature fluctuations, or to prevent any possible "runaway" reaction temperatures.

The processes of this invention may be conducted in one or more reaction steps and more than one reactive stages. The exact number of reaction steps and reactive stages will be governed by the best compromise between capital costs and achieving high catalyst selectivity, activity, lifetime and ease of operability, as well as the intrinsic reactivity of the starting materials in question and the stability of the starting materials and the desired reaction product to the reaction conditions.

Hydroformylation Processes

A preferred process useful in this invention is hydroformylation. Illustrative metal-organophosphorus ligand complex catalyzed hydroformylation processes as described, for example, in U.S. Patent Nos. 4,148,830; 4,593,127; 4,769,498; 4,717,775; 4,774,361; 4,885,401; 5,264,616; 5,288,918; 5,360,938; 5,364,950; and 5,491,266. Accordingly, the hydroformylation processing techniques of this invention may correspond to any known processing techniques. Preferred process are those involving catalyst liquid recycle hydroformylation processes.

In general, such catalyst liquid recycle hydroformylation processes involve the production of aldehydes by reacting an olefinic unsaturated compound with carbon monoxide and hydrogen in the presence of a metal-organophosphorus ligand complex catalyst in a liquid medium that also contains a solvent for the catalyst and ligand. Preferably free organophosphorus ligand is also present in the liquid hydroformylation reaction medium. The recycle procedure generally involves withdrawing a portion of the liquid reaction medium containing the catalyst and aldehyde product from the hydroformylation reactor (i.e., reaction zone), either continuously or

intermittently, and recovering the aldehyde product therefrom in accordance with the separation techniques of this invention.

In a preferred embodiment, the hydroformylation reaction mixtures employable herein includes any mixture derived from any corresponding hydroformylation process that contains at least some amount of four different main ingredients or components, i.e., the aldehyde product, a metal-organophosphorus ligand complex catalyst, free organophosphorus ligand and an organic solubilizing agent, e.g., nonpolar solvent, for said catalyst and said free ligand, said ingredients corresponding to those employed and/or produced by the hydroformylation process from whence the hydroformylation reaction mixture starting material may be derived. It is to be understood that the hydroformylation reaction mixture compositions employable herein can and normally will contain minor amounts of additional ingredients such as those which have either been deliberately employed in the hydroformylation process or formed in situ during said process. Examples of such ingredients that can also be present include unreacted olefin starting material, carbon monoxide and hydrogen gases, and in situ formed type products, such as saturated hydrocarbons and/or unreacted isomerized olefins corresponding to the olefin starting materials, and high boiling liquid aldehyde condensation byproducts, as well as other inert co-solvent, e.g., polar solvent, type materials or hydrocarbon additives, if employed.

The substituted or unsubstituted olefin reactants that may be employed in the hydroformylation processes (and other suitable processes) of this invention include both optically active (prochiral and chiral) and non-optically active (achiral) olefinic unsaturated compounds containing from 2 to 40, preferably 2 to 20, carbon atoms. Such olefinic unsaturated compounds can be terminally or internally unsaturated and be of straight-chain, branched chain or cyclic structures, as well as olefin mixtures, such as obtained from the oligomerization of propene, butene, isobutene, etc. (such as so called

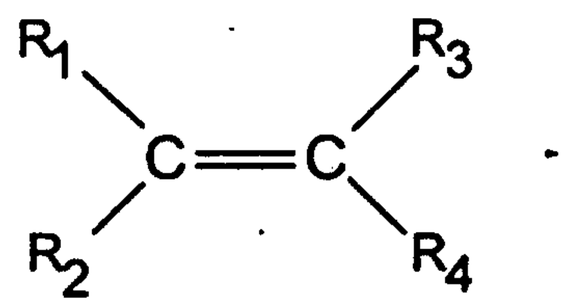
dimeric, trimeric or tetrameric propylene and the like, as disclosed, for example, in U. S. Patent Nos. 4,518,809 and 4,528,403). Moreover, such olefin compounds may further contain one or more ethylenic unsaturated groups, and of course, mixtures of two or more different olefinic unsaturated compounds may be employed as the starting material if desired. For example, commercial alpha olefins containing four or more carbon atoms may contain minor amounts of corresponding internal olefins and/or their corresponding saturated hydrocarbon and that such commercial olefins need not necessarily be purified from same prior to being reacted. Illustrative mixtures of olefinic starting materials that can be employed in the hydroformylation reactions include, for example, mixed butenes, e.g., Raffinate I and II. Further such olefinic unsaturated compounds and the corresponding products derived therefrom may also contain one or more groups or substituents which do not unduly adversely affect the processes of this invention such as described, for example, in U. S. Patent Nos. 3,527,809, 4,769,498 and the like.

Most preferably the subject invention is especially useful for the production of non-optically active aldehydes, by hydroformylating achiral alpha-olefins containing from 2 to 30, preferably 2 to 20, carbon atoms, and achiral internal olefins containing from 2 to 20 carbon atoms as well as starting material mixtures of such alpha olefins and internal olefins.

Illustrative alpha and internal olefins include, for example, ethylene, propylene, 1-butene, 1-pentene, 1-hexene, 1-octene, 1-nonene, 1-decene, 1-undecene, 1-dodecene, 1-tridecene, 1-tetradecene, 1-pentadecene, 1-hexadecene, 1-heptadecene, 1-octadecene, 1-nonadecene, 1-eicosene, 2-butene, 2-methyl propene (isobutylene), 2-methylbutene, 2-pentene, 2-hexene, 3-hexane, 2-heptene, 2-octene, cyclohexene, propylene dimers, propylene trimers, propylene tetramers, butadiene, piperylene, isoprene, 2-ethyl-1-hexene, styrene, 4-methyl styrene, 4-isopropyl styrene, 4-tert-butyl styrene, alpha-

methyl styrene, 4-tert-butyl-alpha-methyl styrene, 1,3-diisopropenylbenzene, 3-phenyl-1-propene, 1,4-hexadiene, 1,7-octadiene, 3-cyclohexyl-1-butene, and the like, as well as, 1,3-dienes, butadiene, pentenoic acids and salts, e.g., salts of 3- and 4-pentenoic acids, alkyl alkenoates, e.g., methyl pentenoate, alkenyl alkanoates, alkenyl alkyl ethers, alkenols, e.g., pentenols, alkenals, e.g., pentenals, and the like, such as allyl alcohol, allyl butyrate, hex-1-en-4-ol, oct-1-en-4-ol, vinyl acetate, allyl acetate, 3-butenyl acetate, vinyl propionate, allyl propionate, methyl methacrylate, vinyl ethyl ether, vinyl methyl ether, allyl ethyl ether, n-propyl-7-octenoate, 3-butenenitrile, 5-hexenamide, eugenol, iso-eugenol, safrole, iso-safrole, anethol, 4-allylanisole, indene, limonene, beta-pinene, dicyclopentadiene, cyclooctadiene, camphene, linalool, and the like.

Illustrative prochiral and chiral olefins useful in the asymmetric hydroformylation processes (and other asymmetric processes) that can be employed to produce enantiomeric product mixtures that may be encompassed by in this invention include those represented by the formula:



(XIII)

wherein R_1, R_2, R_3 and R_4 are the same or different (provided R_1 is different from R_2 or R_3 is different from R_4) and are selected from hydrogen; alkyl; substituted alkyl, said substitution being selected from dialkylamino such as benzylamino and dibenzylamino, alkoxy such as methoxy and ethoxy, acyloxy such as acetoxy, halo, nitro, nitrile, thio, carbonyl, carboxamide, carboxaldehyde, carboxyl, carboxylic ester; aryl including phenyl; substituted aryl including

phenyl, said substitution being selected from alkyl, amino including alkylamino and dialkylamino such as benzylamino and dibenzylamino, hydroxy, alkoxy such as methoxy and ethoxy, acyloxy such as acetoxy, halo, nitrile, nitro, carboxyl, carboxaldehyde, carboxylic ester, carbonyl, and thio; acyloxy such as acetoxy; alkoxy such as methoxy and ethoxy; amino including alkylamino and dialkylamino such as benzylamino and dibenzylamino; acylamino and diacylamino such as acetylbenzylamino and diacetylamino; nitro; carbonyl; nitrile; carboxyl; carboxamide; carboxaldehyde; carboxylic ester; and alkylmercapto such as methylmercapto. It is understood that the prochiral and chiral olefins of this definition also include molecules of the above general formula where the R groups are connected to form ring compounds, e.g., 3-methyl-1-cyclohexene, and the like.

Illustrative optically active or prochiral olefinic compounds useful in asymmetric hydroformylation processes (and other asymmetric processes) of this invention include, for example, p-isobutylstyrene, 2-vinyl-6-methoxy-2-naphthylene, 3-ethenylphenyl phenyl ketone, 4-ethenylphenyl-2-thienylketone, 4-ethenyl-2-fluorobiphenyl, 4-(1,3-dihydro-1-oxo-2H-isoindol-2-yl)styrene, 2-ethenyl-5-benzoylthiophene, 3-ethenylphenyl phenyl ether, propenylbenzene, isobutyl-4-propenylbenzene, phenyl vinyl ether and the like. Other olefinic compounds include substituted aryl ethylenes as described, for example, in U.S. Patent Nos. 4,329,507, 5,360,938 and 5,491,266.

Illustrative of suitable substituted and unsubstituted olefinic starting materials include those permissible substituted and unsubstituted olefinic compounds described in Kirk-Othmer, Encyclopedia of Chemical Technology, Fourth Edition, 1996.

As noted, the hydroformylation processes of this invention involve the use of a metal-organophosphorus ligand complex catalyst

as described hereinabove. Of course mixtures of such catalysts can also be employed if desired. The amount of metal-organophosphorus ligand complex catalyst present in the reaction medium of a given hydroformylation process encompassed by this invention need only be that minimum amount necessary to provide the given metal concentration desired to be employed and which will furnish the basis for at least the catalytic amount of metal necessary to catalyze the particular hydroformylation process involved such as disclosed, for example, in the above-mentioned patents. In general, metal, e.g., rhodium, concentrations in the range of from about 10 parts per million to about 1000 parts per million, calculated as free rhodium, in the hydroformylation reaction medium should be sufficient for most processes, while it is generally preferred to employ from about 10 to 500 parts per million of metal, e.g., rhodium, and more preferably from 25 to 400 parts per million of metal, e.g., rhodium.

In addition to the metal-organophosphorus ligand complex catalyst, free organophosphorus ligand (i.e., ligand that is not complexed with the metal) may also be present in the hydroformylation reaction medium. The free organophosphorus ligand may correspond to any of the above-defined organophosphorus ligands employable herein. It is preferred that the free organophosphorus ligand be the same as the organophosphorus ligand of the metal-organophosphorus ligand complex catalyst employed. However, such ligands need not be the same in any given process. The hydroformylation process of this invention may involve from about 0.1 moles or less to about 400 moles or higher, of free organophosphorus ligand per mole of metal in the hydroformylation reaction medium. Preferably the hydroformylation process of this invention is carried out in the presence of from about 1 to about 200 moles of organophosphorus ligand, and more preferably for organopolyphosphites from about 1.1 to about 4 moles of organopolyphosphite ligand, per mole of metal present in the reaction medium; said amounts of organophosphorus ligand being the sum of

both the amount of organophosphorus ligand that is bound (complexed) to the metal present and the amount of free (non-complexed) organophosphorus ligand present. Since it is more preferred to produce non-optically active aldehydes by hydroformylating achiral olefins, the more preferred organophosphorus ligands are achiral type organophosphorus ligands, especially those encompassed by Formula (I) above, and more preferably those of Formulas (II) and (V) above. Of course, if desired, make-up or additional organophosphorus ligand can be supplied to the reaction medium of the hydroformylation process at any time and in any suitable manner, e.g. to maintain a predetermined level of free ligand in the reaction medium.

The reaction conditions of the hydroformylation processes encompassed by this invention may include any suitable type hydroformylation conditions heretofore employed for producing optically active and/or non-optically active aldehydes. For instance, the total gas pressure of hydrogen, carbon monoxide and olefin starting compound of the hydroformylation process may range from about 1 to about 10,000 psia. In general, however, it is preferred that the process be operated at a total gas pressure of hydrogen, carbon monoxide and olefin starting compound of less than about 2000 psia and more preferably less than about 1000 psia. The minimum total pressure is limited predominately by the amount of reactants necessary to obtain a desired rate of reaction. More specifically the carbon monoxide partial pressure of the hydroformylation process of this invention is preferable from about 1 to about 1000 psia, and more preferably from about 3 to about 800 psia, while the hydrogen partial pressure is preferably about 5 to about 500 psia and more preferably from about 10 to about 300 psia. In general H_2:CO molar ratio of gaseous hydrogen to carbon monoxide may range from about 1:10 to 100:1 or higher, the more preferred hydrogen to carbon monoxide molar ratio being from about 1:10 to about 10:1. Further, the hydroformylation process may be conducted at a reaction temperature from about –25°C to about 200°C.

In general hydroformylation reaction temperatures of about 50°C to about 120°C are preferred for all types of olefinic starting materials. Of course it is to be understood that when non-optically active aldehyde products are desired, achiral type olefin starting materials and organophosphorus ligands are employed and when optically active aldehyde products are desired prochiral or chiral type olefin starting materials and organophosphorus ligands are employed. Of course, it is to be also understood that the hydroformylation reaction conditions employed will be governed by the type of aldehyde product desired.

Accordingly illustrative non-optically active aldehyde products include e.g., propionaldehyde, n-butyraldehyde, isobutyraldehyde, n-valeraldehyde, 2-methyl 1-butyraldehyde, hexanal, hydroxyhexanal, 2-methyl valeraldehyde, heptanal, 2-methyl 1-hexanal, octanal, 2-methyl 1-heptanal, nonanal, 2-methyl-1-octanal, 2-ethyl 1-heptanal, 3-propyl 1-hexanal, decanal, adipaldehyde, 2-methylglutaraldehyde, 2-methyladipaldehyde, 3-methyladipaldehyde, 3-hydroxypropionaldehyde, 6-hydroxyhexanal, alkenals, e.g., 2-, 3- and 4-pentenal, formylvaleric acids and salts, e.g., salts of 5-formylvaleric acid, alkyl 5-formylvalerate, 2-methyl-1-nonanal, undecanal, 2-methyl 1-decanal, dodecanal, 2-methyl 1-undecanal, tridecanal, 2-methyl 1-tridecanal, 2-ethyl, 1-dodecanal, 3-propyl-1-undecanal, pentadecanal, 2-methyl-1-tetradecanal, hexadecanal, 2-methyl-1-pentadecanal, heptadecanal, 2-methyl-1-hexadecanal, octadecanal, 2-methyl-1-heptadecanal, nonodecanal, 2-methyl-1-octadecanal, 2-ethyl 1-heptadecanal, 3-propyl-1-hexadecanal, eicosanal, 2-methyl-1-nonadecanal, heneicosanal, 2-methyl-1-eicosanal, tricosanal, 2-methyl-1-docosanal, tetracosanal, 2-methyl-1-tricosanal, pentacosanal, 2-methyl-1-tetracosanal, 2-ethyl 1-tricosanal, 3-propyl-1-docosanal, heptacosanal, 2-methyl-1-octacosanal, nonacosanal, 2-methyl-1-octacosanal, hentriacontanal, 2-methyl-1-triacontanal, and the like.

Illustrative optically active aldehyde products include (enantiomeric) aldehyde compounds prepared by the asymmetric

hydroformylation process of this invention such as, e.g. S-2-(p-isobutylphenyl)-propionaldehyde, S-2-(6-methoxy-2-naphthyl)propionaldehyde, S-2-(3-benzoylphenyl)-propionaldehyde, S-2-(p-thienoylphenyl)propionaldehyde, S-2-(3-fluoro-4-phenyl)phenylpropionaldehyde, S-2-[4-(1,3-dihydro-1-oxo-2H-isoindol-2-yl)phenyl]propionaldehyde, S-2-(2-methylacetaldehyde)-5-benzoylthiophene and the like.

Illustrative of suitable substituted and unsubstituted aldehyde products include those permissible substituted and unsubstituted aldehyde compounds described in Kirk-Othmer, Encyclopedia of Chemical Technology, Fourth Edition, 1996

In accordance with this invention, the aldehyde product mixtures may be extracted and separated from the other components of the crude reaction mixtures in which the aldehyde mixtures are produced by phase separation as described above.

It is generally preferred to carry out the hydroformylation processes of this invention in a continuous manner. In general, continuous hydroformylation processes are well known in the art and may involve: (a) hydroformylating the olefinic starting material(s) with carbon monoxide and hydrogen in a liquid homogeneous reaction mixture comprising a nonpolar solvent, the metal-organophosphorus ligand complex catalyst, free organophosphorus ligand, and optionally a polar solvent; (b) maintaining reaction temperature and pressure conditions favorable to the hydroformylation of the olefinic starting material(s); (c) supplying make-up quantities of the olefinic starting material(s), carbon monoxide and hydrogen to the reaction medium as those reactants are used up; (d) mixing at least a portion of the reaction medium with a polar solvent to extract the desired aldehyde hydroformylation product(s) from the reaction medium; and (e) recovering the desired aldehyde product(s) by phase separation.

At the conclusion of (or during) the process of this invention, the desired aldehydes may be recovered from the reaction mixtures used in the process of this invention. For instance, in a continuous liquid catalyst recycle process the portion of the liquid reaction mixture (containing aldehyde product, catalyst, etc.) removed from the reaction zone can be passed to a separation zone wherein the desired aldehyde product can be extracted and separated via phase separation from the liquid reaction mixture, and further purified if desired. The remaining catalyst containing liquid reaction mixture may then be recycled back to the reaction zone as may if desired any other materials, e.g., unreacted olefin, together with any hydrogen and carbon monoxide dissolved in the liquid reaction after separation thereof from the aldehyde product.

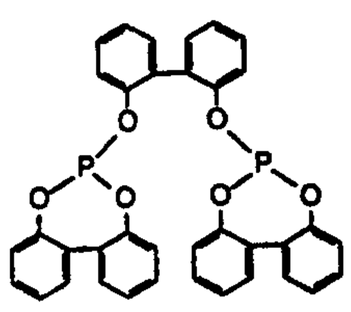
For purposes of this invention, the term "hydrocarbon" is contemplated to include all permissible compounds having at least one hydrogen and one carbon atom. Such permissible compounds may also have one or more heteroatoms. In a broad aspect, the permissible hydrocarbons include acyclic (with or without heteroatoms) and cyclic, branched and unbranched, carbocyclic and heterocyclic, aromatic and nonaromatic organic compounds which can be substituted or unsubstituted.

As used herein, the term "substituted" is contemplated to include all permissible substituents of organic compounds unless otherwise indicated. In a broad aspect, the permissible substituents include acyclic and cyclic, branched and unbranched, carbocyclic and heterocyclic, aromatic and nonaromatic substituents of organic compounds. Illustrative substituents include, for example, alkyl, alkyloxy, aryl, aryloxy, hydroxy, hydroxyalkyl, amino, aminoalkyl, halogen and the like in which the number of carbons can range from 1 to about 20 or more, preferably from 1 to about 12. The permissible substituents can be one or more and the same or different for appropriate organic compounds. This invention is not intended to be

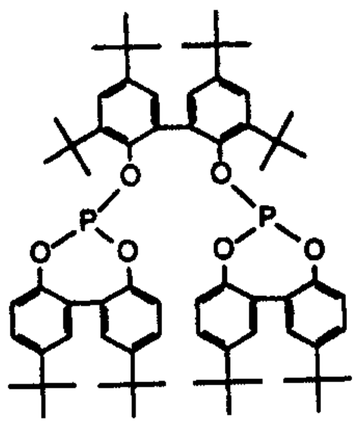
limited in any manner by the permissible substituents of organic compounds.

Certain of the following examples are provided to further illustrate this invention. It is to be understood that all manipulations were carried out under a nitrogen atmosphere unless otherwise stated. Also, all examples were carried out at ambient temperature unless otherwise stated.

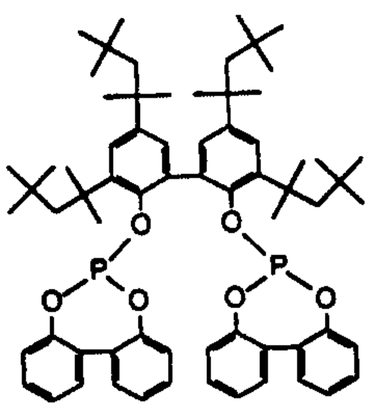
The ligands set out below are used in the following examples.



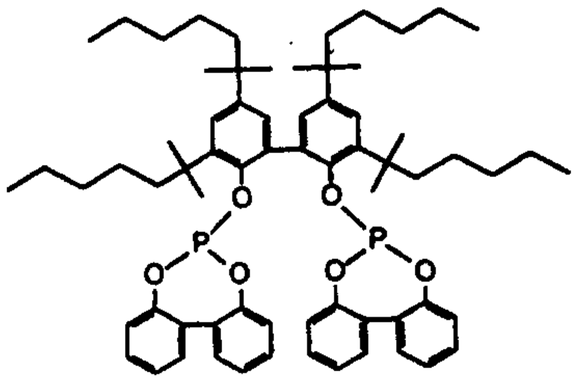
Ligand A



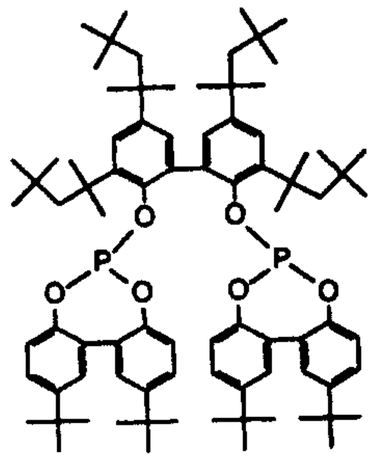
Ligand B



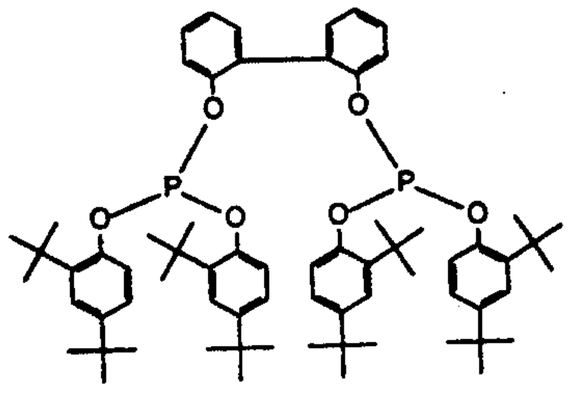
Ligand C



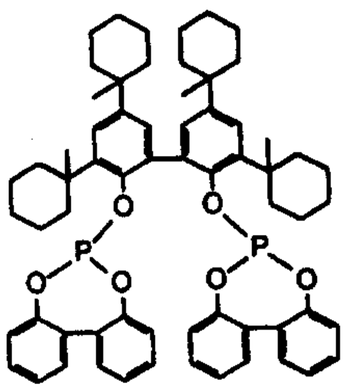
Ligand D



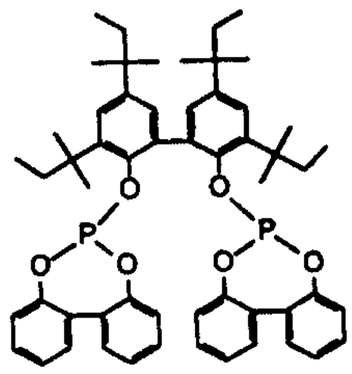
Ligand E



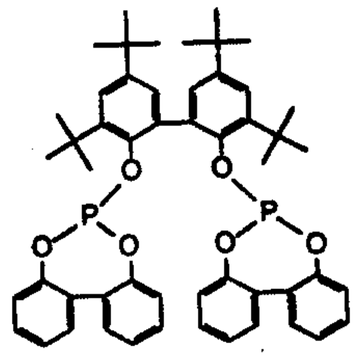
Ligand F



Ligand G

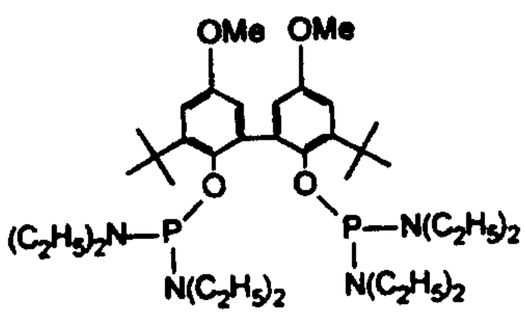


Ligand H

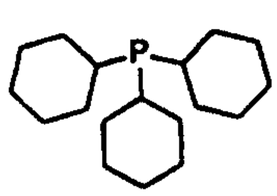


Ligand I

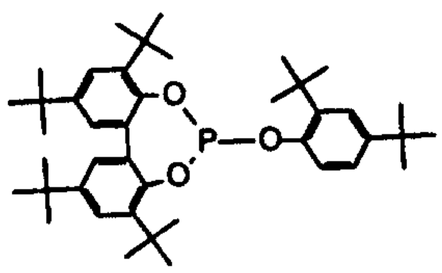
Ligand J



Ligand K



Ligand L



Ligand M

Solubility parameters and Kpartition coefficients of illustrative ligands, certain of which are used in the examples below, are given in the following table.

Table

Ligand	Solubility Parameter (cal/cm^3)	Solubility Parameter (kJ/m^3)	Kpartition*
A	11.2	725	0.04
B	9.1	589	26
C	9.0	582	38
D	9.3	602	116
E	8.6	556	502
F	8.7	563	100
G	9.7	627	19
H	9.6	621	6
I	9.8	634	2.3
J	7.6	492	>100
K	8.5	550	5
L	8.1	524	>100
M	8.6	556	25

*- Kpartition values for hexane:acetonitrile (1:1) solvent system

Comparative Example A

A 1 milliliter aliquot of an acetonitrile solution containing approximately 0.1 percent by weight of Ligand A was added to a small vial. To this vial was then added a 1 milliliter aliquot of hexane. The mixture was vigorously shaken and then allowed to phase separate. The two layers were then separated and analyzed for ligand content by ^{31}P NMR. The partition coefficient Kp of the ligand was found to be 0.04 for the hexane/acetonitrile solvent system.

This example serves as a control experiment to show that the partitioning behavior of an unsubstituted bis-phosphite ligand is non-selective for the hydrocarbon phase. Comparative Example A

provides a control partitioning behavior, as predicted by calculating the solubility parameter (δ) of the ligand, of a bisphosphite ligand which is unsubstituted by alkyl groups.

Example 1

A 1 milliliter aliquot of a hexane solution containing approximately 0.1 percent by weight of Ligand B was added to a small vial. To this vial was then added a 1 milliliter aliquot of acetonitrile. The mixture was vigorously shaken and then allowed to phase separate. The two layers were then separated and each layer analyzed for ligand content by HPLC. The partition coefficient Kp of the ligand was found to be 26 for the hexane/acetonitrile solvent system.

Examples 2 - 7

The procedure described in Example 1 was repeated with the modification of using Ligands C - H in place of Ligand B. In Table A below, the measured values of partition coefficient Kp are summarized for Ligands C - H for the hexane/acetonitrile solvent system.

TABLE A

Example	Ligand	Calculated δ	Kpartition
2	C	9.0	38
3	D	9.3	116
4	E	8.6	502
5	F	8.7	100
6	G	9.7	19

7	H	9.6	6

Examples 8 - 11

The procedure described in Example 1 was repeated with the modification of using Ligands J - M in place of Ligand B. NMR or HPLC was used to determine the amount of ligand in each layer. In Table B below, the measured values of partition coefficient Kp are summarized for Ligands J - M for the hexane/acetonitrile solvent system.

TABLE B

Example	Ligand	Calculated δ	Kpartition
8	J	7.6	>100*
9	K	8.5	5
10	L	8.1	>100*
11	M	8.6	25

*-Kpartition determined using ^{31}P NMR; the indicated ligands were not detected in the acetonitrile phase after extraction.

Examples 12 - 13

The procedure described in Example 1 was repeated with the modification of using other polar solvents in place of acetonitrile and Ligand C in place of Ligand B. The measured values of partition coefficient Kp are summarized for Ligand C for the hexane/polar solvent system in Table C below.

TABLE C

Example	Polar Solvent	Kpartition Ligand C
12	DMSO	68
13	Glutaronitrile	20

Comparative Example B

1.5 milliliters of a catalyst solution containing 79 parts per million of rhodium and 0.05 percent by weight of Ligand A in dry acetonitrile were added to a small vial under nitrogen. To this was added 1.5 milliliters of hexane. The mixture was vigorously mixed then allowed to phase separate. The phases were separated and the rhodium content in each phase determined. The partition coefficient Kp of the rhodium was found to be 0.03 for the hexane/acetonitrile solvent system.

Example 14

To a small vial under nitrogen was added a solution containing 136 parts per million rhodium and 0.6 weight percent of Ligand E in hexane under 50 psig syn gas (1:1 CO:H_2). To this vial was added an equal volume of acetonitrile. The vial was vigorously shaken, then allowed to settle. The two phases were then separated, and the amount of rhodium in each phase determined. The partition coefficient Kp of the ligand was found to be 52 for the hexane/acetonitrile solvent system.

Examples 15 - 16

The procedure described in Example 14 was repeated with the modification of using Ligands B and C in place of Ligand E. The concentrations of rhodium and ligand initially in the hexane solution are given in Table D together with the partition coefficient Kp of the ligand for the hexane/acetonitrile solvent system.

TABLE D

Example	Ligand	Ligand (weight percent	Rhodium (parts per million)	Kpartition
15	B	1.5	318	34
16	C	0.8	222	28

Examples 17 - 23

The procedure described in Example 14 was repeated with the modification of using the solvents indicated in Table E and using Ligands B, C and E. The measured values of partition coefficient Kp are summarized for Ligands B, C and E for the various solvent systems in Table C below.

TABLE E

Example	Ligand	Ligand (weight percent)	Rhodium (parts per million)	Polar Solvent	Kpartition
17	B	0.8	223	acetonitrile	19
18	B	0.8	223	DMSO	124
19	C	0.8	222	DMSO	42
20	C	0.8	222	Glutaronitrile	43
21	E	0.6	136	DMSO	79
22	E	0.6	120	acetonitrile	250
23	E	0.6	120	DMSO	128

Examples 24 - 25

The procedure described in Example 14 was repeated with the modification of using acetonitrile containing 1 percent by

weight water in the place of anhydrous acetonitrile. The ligand type, ligand concentration, and rhodium concentration were also modified as described in Table F below. In Table F, polar solvent W is acetonitrile that contains 1 percent by weight of water.

TABLE F

Example	Ligand	Ligand (weight percent)	Rhodium (parts per million)	Polar Solvent	Kpartition
24	B	0.8	223	W	27
25	E	0.6	120	W	352

Examples 26 - 32

A hexane solution was prepared containing 0.6 percent by weight of Ligand E and 120 parts per million of rhodium. The solution was placed under 50 psig of H_2:CO (1:1). An aliquot of this solution was then transferred to a small container. Aldehyde was optionally added to the catalyst solution. To this mixture was then added an equal volume of a polar-solvent. In Table G below, polar solvent A is anhydrous acetonitrile, polar solvent W is acetonitrile that contains 1 percent by weight of water, and polar solvent C is DMSO. In Table G, aldehyde B is butyraldehyde, aldehyde V is valeraldehyde, and N indicates the absence of any aldehyde. [Aldehyde] N also indicates no added aldehyde. The mixture was vigorously shaken for several minutes then allowed to settle. The two phases which had formed were then separated from one another. The polar phase was then extracted two times with a nonpolar solvent. After the extractions, the amount of rhodium contained in the polar phase (parts per billion (ppb)

of Final [Rhodium]) was determined. The results of the extraction experiments are shown in Table G.

TABLE G

Example	Aldehyde	[Aldehyde]	Polar Solvent	Final [Rhodium] ppb
26	N	N	A	237
27	N	N	W	381
28	N	N	C	1148
29	B	5.2	A	196
30	B	39.2	A	1628
31	V	24.3	A	252
32	V	5.21	A	196

Examples 33 - 35

The procedure described in Examples 26 - 32 was repeated with the modification of using 0.8 percent by weight of Ligand B in place of Ligand E, and using 223 parts per million of rhodium instead of using 120 parts per million of rhodium. Aldehyde was not added to the solutions. In Table H below, polar solvent A is anhydrous acetonitrile, polar solvent W is acetonitrile that contains 1 percent by weight of water, and polar solvent C is DMSO. Table H summarizes the results obtained from the extraction experiments.

TABLE H

Example	Polar Solvent	Final [Rhodium] parts per million

33	A	5
34	W	1
35	C	2

Examples 36 - 38

Hexane was added to a valeraldehyde solution containing ligand and rhodium under 50 psig of H_2:CO (1:1). The concentration of rhodium and the percent by weight of valeraldehyde were then determined. Acetonitrile was then added to the solution to effect phase separation. The two phases were then separated. The polar phase was extracted two times with hexane. The amount of rhodium remaining in the polar phase after the extractions was then determined. In Table I, the ratio of the weight of acetonitrile phase added to the weight of catalyst containing phase (after hexane addition) is reported as "acetonitrile/catalyst", the concentration of ligand in the valeraldehyde prior to hexane addition is given as "[Ligand]", the percent by weight of valerladehyde in solution after the addition of hexane (and prior to the addition of acetonitrile) is given as "[aldehyde]", the concentration of rhodium in parts per million (ppm) prior to extraction is reported as "Initial [Rhodium]", and the concentration of rhodium in parts per million (ppm) in the polar phase after extraction is reported as "Final [Rhodium]".

TABLE I

Example	Ligand	[Ligand] (weight percent)	[Aldehyde] (weight percent)	Acetonitrile Catalyst	Initial [Rhodium] (parts per million)	Final [Rhodium] (parts per million)
36	C	0.5	37.3	1.7	99	5
37	C	0.2	16.1	0.56	38	4
38	H	0.4	34.2	0.83	121	22

Example 39

A catalyst solution was prepared with 21.3 milligrams of dicarbonylacetylacetonato rhodium (I) (622 parts per million), 0.172 grams of trioctylphosphine, 10.0 grams of hexane, and 10.0 grams of ethanol. The catalyst (20.0 milliliters, 14.5 grams) and n-valeraldehyde (4.0 grams, 5.0 milliliters) was charged to a 150 milliliter Parr reactor. The reactor was then heated with a band heater to 93°C, which resulted in a partial pressure of 40 psig upon equilibration. The reactor's pressure was then adjusted to 500 psig with H_2:CO (1:1). Pressure was maintained between 500 and 450 psig until no further reaction had occurred (approximately 140 minutes). At this point, the catalyst containing solution was discharged from the reactor. Gas chromatography analysis indicated that the n-valeraldehyde had been converted to 1-pentanol. 2.0 grams of the catalyst solution was transferred to a vial. To this was added 2.0 grams of hexane and 4.0 grams of acetonitrile. The mixture was vigorously shaken for several minutes, then allowed phase separate and allowed to stand for a couple of days. The layers were then separated and analyzed for rhodium content. The partition coefficient Kp of the rhodium was found to be 12.7 for the hexane/acetonitrile solvent system.

Example 40

A solution was prepared containing 88 parts per million of rhodium, 0.44 percent by weight of Ligand E, 27 percent by weight of Texanol commercially available from Eastman Chemical Company, and 73 percent by weight of hexane. To this mixture was added an equal volume of acetonitrile. The mixture was shaken for 30 minutes, then allowed to settle and phase separate for several hours. The two layers were then separated, and analyzed for content. The partition coefficient Kp of the catalyst is summarized in Table J below, together

with the volume ratio of the two phases defined as Vratio = volume of the catalyst containing phase after extraction/volume of the extracting solution phase after extraction, and the selectivity of the extraction defined as Selectivity = Kpartition of catalyst / Kpartition organic material being separated from catalyst.

TABLE J

Kpartition catalyst	Kpartition Texanol	Vratio	Selectivity
84	0.4	5.6	210

Example 41

A solution was prepared containing 60 parts per million of rhodium, 0.2 percent by weight of Ligand E, 1.1 percent by weight of n-butanol, 48 percent by weight of Texanol commercially available from Eastman Chemical Company, and 49 percent by weight of toluene. To this mixture was added an equal volume of acetonitrile containing water in a 4/1 ratio. The mixture was shaken for 30 minutes, then allowed to settle and phase separate over several hours. The two phases were then separated and analyzed for content. In Table K below, partition coefficient Kp of the catalyst and Texanol as well as the volume ratio of the two phases defined as Vratio = volume of the catalyst containing phase after extraction/volume of the extracting solution phase after extraction is summarized.

TABLE K

Kpartition catalyst	Kpartition Texanol	Vratio	Selectivity
69	96	14	0.87

Example 42

Solutions were prepared containing equal volumes of hexane and acetonitrile. To each solution was added a polar organic molecule identified in Table L below. The mixture was vigorously shaken, then allowed to settle and phase separate. The two phases were then analyzed for content of polar molecule by GC. In Table L, the percent by weight of polar molecule added to the hexane/acetonitrile solvent mixture together with Kpartition is given for various polar molecules.

Table L

Polar molecule	wt%	Kpartition
propionaldehyde	7.5	9.2
butyraldehyde	5.2	3.2
valeraldehyde	5.5	2.0
3-pentenenitrile	4.7	50

Although the invention has been illustrated by certain of the preceding examples, it is not to be construed as being limited thereby; but rather, the invention encompasses the generic area as hereinbefore disclosed. Various modifications and embodiments can be made without departing from the spirit and scope thereof.

CLAIMS

1. A process for separating one or more products from a reaction product fluid comprising a metal-organophosphorus ligand complex catalyst, optionally free organophosphorus ligand, a nonpolar solvent, a polar solvent containing less than about 4 weight percent water, and said one or more products, wherein said process comprises (1) mixing said reaction product fluid to obtain by phase separation a non-polar phase comprising said metal-organophosphorus ligand complex catalyst, optionally free organophosphorus ligand and said nonpolar solvent and a polar phase comprising said one or more products and polar solvent, and (2) recovering said polar phase from said nonpolar phase; wherein said organophosphorus ligand has a partition coefficient between the nonpolar solvent and the polar solvent of greater than about 5, and said one or more products have a partition coefficient between the polar solvent and the nonpolar solvent of greater than about 0.5.

2. A process for separating one or more products from a reaction product fluid comprising a metal-organophosphorus ligand complex catalyst, optionally free organophosphorus ligand, a nonpolar solvent and said one or more products, wherein said process comprises (1) mixing said reaction product fluid with a polar solvent containing less than about 4 weight percent water, to obtain by phase separation a non-polar phase comprising such metal-organophosphorus ligand complex catalyst, optionally free organophosphorus ligand and said nonpolar solvent and a polar phase comprising said one or more products and polar solvent, and (2) recovering said polar phase from said nonpolar phase; wherein said organophosphorus ligand has a partition coefficient between the nonpolar solvent and the polar solvent of greater than about 5, and said one or more products have a partition coefficient between the polar solvent and the nonpolar solvent of greater than about 0.5.

3. A process for producing one or more products comprising: (1) reacting one or more reactants in the presence of a metal-organophosphorus ligand complex catalyst, optionally free organophosphorus ligand, a nonpolar solvent and a polar solvent containing less than about 4 weight percent water, to form a multiphase reaction product fluid; and (2) separating said multiphase reaction product fluid to obtain one phase comprising said one or more reactants, metal-organophosphorus ligand complex catalyst, optionally free organophosphorus ligand and nonpolar solvent and at least one other phase comprising said one or more products and polar solvent; wherein said organophosphorus ligand has a partition coefficient between the nonpolar solvent and the polar solvent of greater than about 5, and said one or more products have a partition coefficient between the polar solvent and the nonpolar solvent of greater than about 0.5.

4. A process for producing one or more products comprising: (1) reacting one or more reactants in the presence of a metal-organophosphorus ligand complex catalyst, optionally free organophosphorus ligand and a nonpolar solvent to form a reaction product fluid; (2) mixing said reaction product fluid with a polar solvent containing less than about 4 weight percent water, to form a multiphase reaction product fluid; and (3) separating said multiphase reaction product fluid to obtain one phase comprising said one or more reactants, metal-organophosphorus ligand complex catalyst, optionally free organophosphorus ligand and nonpolar solvent and at least one other phase comprising said one or more products and polar solvent; wherein said organophosphorus ligand has a partition coefficient between the nonpolar solvent and the polar solvent of greater than about 5, and said one or more products have a partition coefficient between the polar solvent and the nonpolar solvent of greater than about 0.5.

5. The process of claim 3 comprising comprising: (1) reacting an olefinic unsaturated compound with carbon monoxide and hydrogen in the presence of a metal-organophosphorus ligand complex catalyst, optionally free organophosphorus ligand, a nonpolar solvent and a polar solvent to form a multiphase reaction product fluid; and (2) separating said multiphase reaction product fluid to obtain one phase comprising said olefinic unsaturated compound, metal-organophosphorus ligand complex catalyst, optionally free organophosphorus ligand and nonpolar solvent and at least one other phase comprising aldehyde products and polar solvent; wherein said organophosphorus ligand has a partition coefficient between the nonpolar solvent and the polar solvent of greater than about 5, and said aldehydes have a partition coefficient between the polar solvent and the nonpolar solvent of greater than about 0.5.

6. The process of claim 4 comprising: (1) reacting an olefinic unsaturated compound with carbon monoxide and hydrogen in the presence of a metal-organophosphorus ligand complex catalyst, optionally free organophosphorus ligand and a nonpolar solvent to form a reaction product fluid; (2) mixing said reaction product fluid with a polar solvent to form a multiphase reaction product fluid; and (3) separating said multiphase reaction product fluid to obtain one phase comprising said olefinic unsaturated compound, metal-organophosphorus ligand complex catalyst, optionally free organophosphorus ligand and nonpolar solvent and at least one other phase comprising aldehyde products and polar solvent; wherein said organophosphorus ligand has a partition coefficient between the nonpolar solvent and the polar solvent of greater than about 5, and said aldehydes have a partition coefficient between the polar solvent and the nonpolar solvent of greater than about 0.5.

7. The process of claim 1 wherein said organophosphorus ligand has a partition coefficient between the nonpolar solvent and the polar solvent of greater than about 7.5.

8. The process of claim 2 wherein said organophosphorus ligand has a partition coefficient between the nonpolar solvent and the polar solvent of greater than about 7.5.

9. The process of claim 1 wherein said one or more products have a partition coefficient between the polar solvent and the nonpolar solvent of greater than about 0.75.

10. The process of claim 2 wherein said one or more products have a partition coefficient between the polar solvent and the nonpolar solvent of greater than about 0.75.

11. The process of claim 3 which comprises a hydroformylation, hydroacylation selected from intramolecular and intermolecular hydroacylation, hydrocyanation, hydroamidation, hydroesterification, aminolysis, alcoholysis, hydrocarbonylation, hydroxycarbonylation, carbonylation, isomerization or transfer hydrogenation process.

12. The process of claim 1 wherein said nonpolar solvent is selected from alkanes, cycloalkanes, alkenes, aldehydes, ketones, ethers, esters, amines, aromatics, silanes, silicones and carbon dioxide.

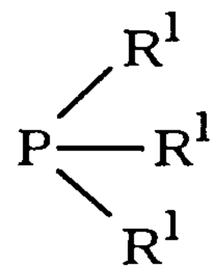
13. The process of claim 1 wherein said polar solvent is selected from nitriles, lactones, pyrrolidones, formamides and sulfoxides.

14. The process of claim 12 wherein said nonpolar solvent is selected from propane, 2,2-dimethylpropane, butane, 2,2-dimethylbutane, pentane, isopropyl ether, hexane, triethylamine, heptane, octane, nonane, decane, isobutyl isobutyrate, tributylamine, undecane, 2,2,4-trimethylpentyl acetate, isobutyl heptyl ketone, diisobutyl ketone, cyclopentane, cyclohexane, isobutylbenzene, n-nonylbenzene, n-octylbenzene, n-butylbenzene, p-xylene, ethylbenzene, 1,3,5-trimethylbenzene, m-xylene, toluene, o-xylene, decene, docenene, tetradecene, and heptadecanal.

15. The process of claim 13 wherein said polar solvent is selected from propionitrile, 1,3-dioxolane, 3-methoxypropionitrile, N-methylpyrrolidone, N,N-dimethylformamide, 2-methyl-2-oxazoline, adiponitrile, acetonitrile, epsilon caprolactone, glutaronitrile, 3-methyl-2-oxazolidinone, dimethyl sulfoxide and sulfolane.

16. The process of claim 1 wherein said metal-organophosphorus ligand complex catalyst comprises rhodium complexed with an organophosphorus ligand represented by the formula:

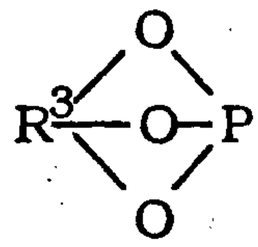
(i) a triorganophosphine ligand represented by the formula:



wherein R^1 is the same or different and represents a substituted or unsubstituted monovalent hydrocarbon radical containing from 1 to 24 carbon atoms;

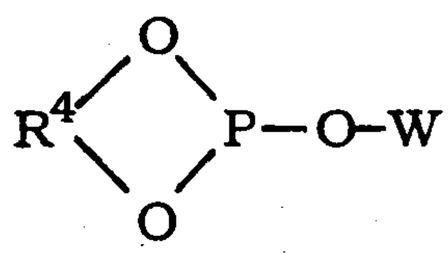
64693-5723

(ii) a monoorganophosphite represented by the formula:



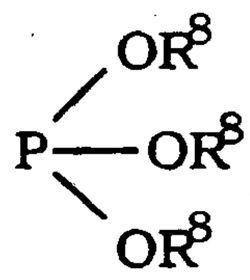
wherein R^3 represents a substituted or unsubstituted trivalent hydrocarbon radical containing from 4 to 40 carbon atoms;

(iii) a diorganophosphite represented by the formula:



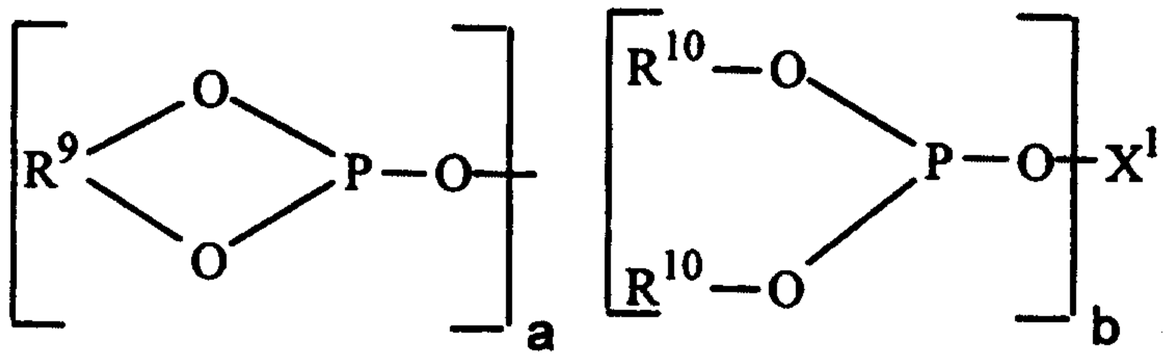
wherein R^4 represents a substituted or unsubstituted divalent hydrocarbon radical containing from 4 to 40 carbon atoms and W represents a substituted or unsubstituted monovalent hydrocarbon radical containing from 1 to 18 carbon atoms;

(iv) a triorganophosphite represented by the formula:



wherein each R^8 is the same or different and represents a substituted or unsubstituted monovalent hydrocarbon radical; and

(v) an organopolyphosphite containing two or more tertiary (trivalent) phosphorus atoms represented by the formula:



wherein X^1 represents a substituted or unsubstituted n-valent hydrocarbon bridging radical containing from 2 to 40 carbon atoms, each R^9 is the same or different and represents a divalent hydrocarbon radical containing from 4 to 40 carbon atoms, each R^{10} is the same or different and represents a substituted or unsubstituted monovalent hydrocarbon radical containing from 1 to 24 carbon atoms, a and b can be the same or different and each have a value of 0 to 6, with the proviso that the sum of a + b is 2 to 6 and n equals a + b.

17. The process of claim 5 wherein said olefinic unsaturated compound comprises one or more pentenoic acids and/or salts and said aldehydes comprise one or more formylvaleric acids and/or salts.

18. The process of claim 6 wherein said olefinic unsaturated compound comprises one or more pentenoic acids and/or salts and said aldehydes comprise one or more formylvaleric acids and/or salts.