Functionalized Phosphine Ligands in Transition Metal-catalysed Organic Synthesis. Nickel(0)-catalysed Cycloaddition of Terminally Unsubstituted Diynes and Carbon Dioxide to Bicyclic 2-Pyrones

Tetsuo Tsuda,* Shohei Morikawa, and Takeo Saegusa*

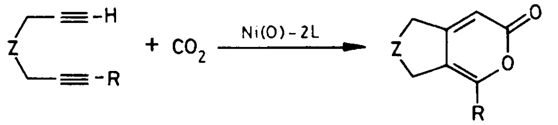
Department of Synthetic Chemistry, Faculty of Engineering, Kyoto University, Yoshida, Kyoto 606, Japan

A functionalized trialkylphosphine ligand (**1a**) containing a pyridyl group has effected the Ni(0)-catalysed cycloaddition of terminally unsubstituted diynes with CO_2 to give bicyclic 2-pyrones, for which ordinary trialkylphosphine ligands are not effective.

Tertiary phosphine ligands play a crucial role in transition metal-catalysed synthetic organic reactions.[1] Commercially available tertiary phosphines such as trialkylphosphines, triarylphosphines, and bis(diphenylphosphino)alkanes are usually used for these reactions, except transition metal-catalysed asymmetric synthesis[2] where chiral phosphine ligands with a variety of functional groups have been developed. Functionalized tertiary phosphines containing co-ordinating heteroatoms such as nitrogen, oxygen, and sulphur have attracted considerable attention[3] because these 'hard' ligand components dissociate readily, generating a vacant site on the metal for substrate binding. Their co-ordination chemistry has been extensively studied, but there are few examples of their use in the synthesis of complex organic molecules.

Here we report that a novel 1-(2′-pyridyl)-2-(di-n-butylphosphino)ethane ligand (**1a**),[4] *i.e.*, a trialkylphosphine ligand containing a pyridyl group, is effective for the Ni(0)-catalysed cycloaddition of terminally unsubstituted diynes (**2a**—**c**) with carbon dioxide to give bicyclic 2-pyrones (**3**) (equation 1). Bicyclic 2-pyrones are useful intermediates in organic synthesis.[5] Monocyclic and annulated 2-pyrone ring systems are also found in several biologically active natural products.[5a—c] Recently we reported that monodentate trialkylphosphine ligands such as tri-n-octylphosphine and tricyclohexylphosphine (PCy_3) are effective for Ni(0)-catalysed bicyclic 2-pyrone formation from terminally dialkyl-substituted diynes and CO_2,[6] but not for the reaction of the parent unsubstituted diyne (**2b**).

When octa-1,7-diyne (**2b**) was treated with CO_2 under pressure in tetrahydrofuran (THF) at 100 °C in the presence of a Ni(0) catalyst (10 mol%) generated from $Ni(cod)_2$ (cod = cyclo-octa-1,5-diene) and two equiv. of (**1a**), 5,6,7,8-tetrahydro-3*H*-2-benzopyran-3-one (**3b**) was obtained in 68% yield (Table 1). The reduced Ni(0) catalyst (5.0 mol%) also gave (**3b**) efficiently. Monodentate trialkylphosphine ligands, which are effective for the reaction of the dialkyl-substituted diynes, did not produce good results: PEt_3, $PBu^n{}_3$, and $P(C_8H_{17}\text{-n})_3$ gave (**3b**) only in 10—20% yields and PCy_3 did not produce (**3b**). The activity of a combined ligand system $Bu^n{}_3P$–pyridine was not high and the pyridine solvent markedly retarded the action of (**1a**). Another functionalized phosphine ligand (**1b**), which may form a five-membered



(1)

(2) (3)

a; Z = CH_2, R = H
b; Z = CH_2CH_2, R = H
c; Z = CH_2CH_2, R = Pr^i

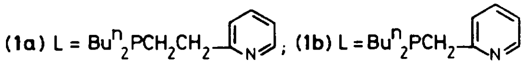


Table 1. Ni(0)-catalysed bicyclic 2-pyrone synthesis from terminally unsubstituted diynes and CO_2.[a]

Diyne (2)	Ligand (L)	Temp./°C	Bicyclic 2-pyrone (3),	[b]Yield/%
(**2a**)	(**1b**)	80	(**3a**)	10
(**2a**)	(**1a**)	80	(**3a**)	65 [44][c]
(**2b**)	(**1b**)	100	(**3b**)	24
(**2b**)	(**1a**)	120	(**3b**)	61
(**2b**)	(**1a**)	100	(**3b**)	68 [50][c]
(**2b**)	(**1a**)	80	(**3b**)	57
(**2b**)	(**1a**)	100	(**3b**)	5[d]
(**2b**)	$Bu^n{}_3P$–Pyridine (1 : 1)	100	(**3b**)	27
(**2b**)	PMe_3	100	(**3b**)	2
(**2b**)	PEt_3	100	(**3b**)	19
(**2b**)	$PBu^n{}_3$	100	(**3b**)	14
(**2b**)	$PBu^t{}_3$	100	(**3b**)	2
(**2b**)	PCy_3	100	(**3b**)	0
(**2b**)	$PC_8H_{17}{}^n{}_3$	100	(**3b**)	18
(**2c**)	(**1a**)	80	(**3c**)	47
(**2c**)	PEt_3	80	(**3c**)	7
(**2c**)	PCy_3	80	(**3c**)	0

[a] (**2**) (0.50 mmol), $Ni(cod)_2/(2)$ = 0.10; $L/Ni(cod)_2$ = 2; CO_2 (initial pressure at room temperature 50 kg cm^{-2}); THF (20 ml), 20 h. [b] Yield determined by g.c. using an internal standard. Products (**3a**—**c**) showed spectroscopic data and elemental composition (high resolution m.s.) in accord with the proposed structures. [c] The value in brackets is the isolated yield [%] determined by p.l.c. [d] (**2b**) (0.25 mmol), pyridine (10 ml).

chelated ring, was less efficient than (**1a**). These findings demonstrate the uniqueness of the functionalized phosphine ligand (**1a**) and suggest that intramolecular co-ordination of the pyridyl group to the nickel atom to form a six-membered chelated ring may be responsible for its effectiveness. The bicyclic 2-pyrone (**3a**) with a fused five-membered ring was similarly produced from (**2a**) and CO_2 by the $Ni(cod)_2$–(**1a**) catalyst.

The ligand (**1a**) was also effective for the cycloaddition of the terminally monoalkyl-substituted diyne (**2c**) with CO_2, which proceeded regioselectively to give exclusively 5,6,7,8-tetrahydro-1-isopropyl-3*H*-2-benzopyran-3-one (**3c**) without formation of the corresponding 4-isopropyl-substituted regioisomer. This is synthetically significant and suggests[6,7] that CO_2 reacts first with the unsubstituted C≡C bond of (**2c**) through the intermediacy of the zero-valent nickel atom.

Coupled with our previous work,[6] the present study using the parent unsubstituted diynes indicates that Ni(0)-catalysed cycloaddition of diynes and CO_2 provides a general and convenient method of preparing bicyclic 2-pyrones in one step.

Received, 11th July 1988; Com. 8/02802H

References

1 For example, 'Comprehensive Organometallic Chemistry,' vol. 8, eds. G. Wilkinson, F. G. A. Stone, and E. W. Abel, Pergamon, New York, 1982.

2 For example, H. B. Kagan, in 'Comprehensive Organometallic Chemistry', vol. 8, eds. G. Wilkinson, F. G. A. Stone, and E. W. Abel, Pergamon, New York, 1982, p. 463.

3 J. C. Jeffrey and T. B. Rauchfuss, *Inorg. Chem.*, 1979, **18**, 2658; M. Bressan, F. Morandini, and P. Rigo, *J. Organomet. Chem.*, 1983, **247**, C8; E. Lindner, H. Rauleder, and P. Wegner, *Z. Naturforsch., Teil B*, 1984, **39**, 1224; S.-E. Bouaoud, P. Braunstein, D. Grandjean, D. Matt, and D. Novel, *Inorg. Chem.*, 1986, **25**, 3765, and references therein.

4 The ligand (**1a**) was prepared according to the method used for the preparation of phosphinoacetonitriles, see O. Dahl and F. K. Jensen, *Acta Chem. Scand., Ser. B*, 1975, **29**, 863.

5 (a) J. Staunton, in 'Comprehensive Organic Chemistry,' vol. 8, ed. P. G. Sammes, Pergamon, Oxford, 1979, p. 225; (b) G. P. Ellis, in 'Comprehensive Heterocyclic Chemistry,' vol. 3, eds. A. J. Boulton and A. McKillop, Pergamon, Oxford, 1984, p. 645; (c) R. K. Dieter and J. R. Fishpaugh, *J. Org. Chem.*, 1983, **48**, 4439, and references therein; (d) M. E. Jung, J. A. Lowe, M. A. Lyster, M. Node, R. W. Pfluger, and R. W. Brown, *Tetrahedron*, 1984, **40**, 4751.

6 T. Tsuda, S. Morikawa, R. Sumiya, and T. Saegusa, *J. Org. Chem.*, 1988, **53**, 3140. See also T. Tsuda, R. Sumiya, and T. Saegusa, *Synth. Commun.*, 1987, **17**, 147.

7 H. Hoberg, D. Schaeffer, G. Burkhart, C. Krüger, and M. J. Romao, *J. Organomet. Chem.*, 1984, **266**, 203.