Palladium(II)-catalysed Asymmetric Cyclisation of 2-Allylphenols by the Use of Optically Active β-Pinene

By TAKAHIRO HOSOKAWA,* SHYOGO MIYAGI, SHUN-ICHI MURAHASHI, and AKIO SONODA

(Department of Chemistry, Faculty of Engineering Science, Osaka University, Machikaneyama, Toyonaka, Osaka, Japan 560)

Summary The palladium(II)-catalysed asymmetric cyclisation of 2-(but-2-enyl)phenol (**1**) to optically active 2,3-dihydro-2-vinylbenzofuran (**3**) can be achieved in 12% optical yield by using a catalytic amount of (—)-β-pinene, while in the presence of excess of β-pinene, cyclisation of (**1**) does not occur.

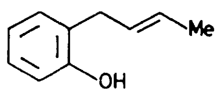
THE oxidative ring closure of 2-allylphenols by palladium(II) salts generally gives 2-substituted benzo- and/or dihydrobenzo-furans,[1] and cyclisations of this type have been shown to be useful for synthesizing a variety of heterocyclic compounds.[2] We report here that the Pd^{II}-catalysed asymmetric synthesis of 2,3-dihydrobenzofurans from the 2-

allylphenols (**1**) and (**2**) is accomplished by using a catalytic amount of β-pinene as the source of chirality. This is the first demonstration of catalytic, asymmetric oxidative cyclisation of olefins, and the use of an optically active olefin as the chiral source provides a probe to study the nature of the reactive Pd^{II} species involved in this type of reaction.

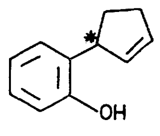
An excess of (*S*)-2,3-dihydro-2-vinylbenzofuran (**3**) was obtained by cyclisation of 2-(but-2-enyl)phenol (**1**) with palladium(II) acetate in the presence of (−)-β-pinene in 12% optical yield as follows. Into a heterogeneous stirred mixture of Pd(OAc)$_2$ (1 mmol), Cu(OAc)$_2$·H$_2$O (10 mmol), and (−)-β-pinene {1 mmol; $[\alpha]_D^{25}$ −20·0 (neat)} in MeOH–H$_2$O (19 : 1 v/v) was added the allylphenol (**1**; 10 mmol; *trans/cis* 93/7) at 35 °C under O$_2$ (*ca.* 1 atm.). The allylphenol (**1**) was completely consumed within 3 h. After the usual work-up, distillation gave a 62% combined yield of 2,3-dihydro-2-vinylbenzofuran (**3**) {$[\alpha]_D^{25}$ + 2·79 (CCl$_4$, *c* 4·19) after g.l.c.} and 2-ethylbenzofuran (**4**) in the ratio 89 : 11. The optical yield and absolute configuration of (**3**) were determined by conversion into ethyl 2,3-dihydrobenzofuran-2-carboxylate of known optical rotation and absolute configuration,[3] by oxidation with potassium permanganate followed by esterification.

When excess of β-pinene was used, cyclisation of (**1**) did not occur; in the presence of 2 equiv. of β-pinene with respect to Pd(OAc)$_2$, the extent of cyclisation to (**3**) was <1% after 24 h. In contrast, in the presence of excess of (−)- or (+)-α-pinene, the cyclisation proceeded smoothly,[†] but the product (**3**) was optically inactive. These results indicate that co-ordination of the substrate molecule to Pd^{II} is in competition with co-ordination of the olefinic additives, and that the *exo*-double bond of β-pinene more easily co-ordinates to Pd^{II} than does the internal double bond of (**1**). Co-ordination of β-pinene probably leads to a catalytic species having a π-allylic ligand such as (**7**), since bis[acetoxy-(7,1,2-η-pinene)palladium(II)][‡] reacts catalytically with (**1**) [(**1**)/Pd = 10/1] under the foregoing conditions, affording optically active (**3**) in similar optical yield: $[\alpha]_D^{25}$ + 3·01 (CCl$_4$, *c* 7·13) [(**3**)/(**4**) = 87/13 in 71% combined yield; 5 h].

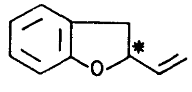
In contrast to the cyclisation of (**1**), (±)-2-(cyclopent-2-enyl)phenol (**2**) reacts with Pd(OAc)$_2$ even in the presence of excess of β-pinene. The use of 10 equiv. of (−)-β-pinene with respect to Pd(OAc)$_2$ under similar conditions led to a 93 : 7 mixture of (**5**) and (**6**) having a *cis*-configuration at C-3a and C-8b[4] (16% yield after 3 h); $[\alpha]_D^{25}$ of mixture + 7·7 (CCl$_4$, *c* 0·57). In this case the recovered (**2**) was also optically active, $[\alpha]_D^{25}$ + 0·31 (CCl$_4$, *c* 3·76). Thus, in this system, co-ordination of the carbon–carbon double bond of (**2**) to Pd^{II} is not prevented to a significant extent by the presence of excess of β-pinene.



(1)



(2)



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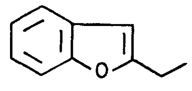

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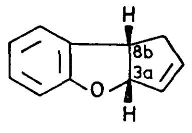
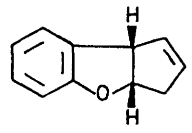


(5)



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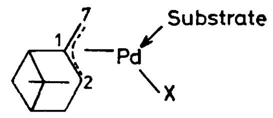

(7)

(*Received, 2nd May* 1978; *Com.* 455.)

[†] When 10 equiv. of α-pinene was used, the cyclisation of (**1**) was completed within 2 h. Commercially available (−)- or (+)-α-pinene contains *ca.* 5% of β-pinene, which was removed by treatment with Pd(OAc)$_2$ followed by distillation.

[‡] Prepared by treatment of the π-allyl palladium(II) chloride dimer derived from (−)-β-pinene and PdCl$_2$ (B. M. Trost and P. E. Strege, *Tetrahedron Letters*, 1974, 2603) with AgOAc.

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[4] The *cis*-configuration was assigned on the basis of n.m.r. spectroscopy; see, T. Hosokawa, S. Miyagi, S-I. Murahashi, A. Sonoda, Y. Matsuura, S. Tanimoto, and M. Kakudo, *J. Org. Chem.*, 1978, **43**, 719.