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THE SYNTHESIS OF ANTHRAPHOS, A CONFORMATIONALLY RIGID, C_2-SYMMETRIC DIPHOSPHINE AND THE X-RAY CRYSTAL STRUCTURE OF [Rh(COD)(ANTHRAPHOS)]BF_4

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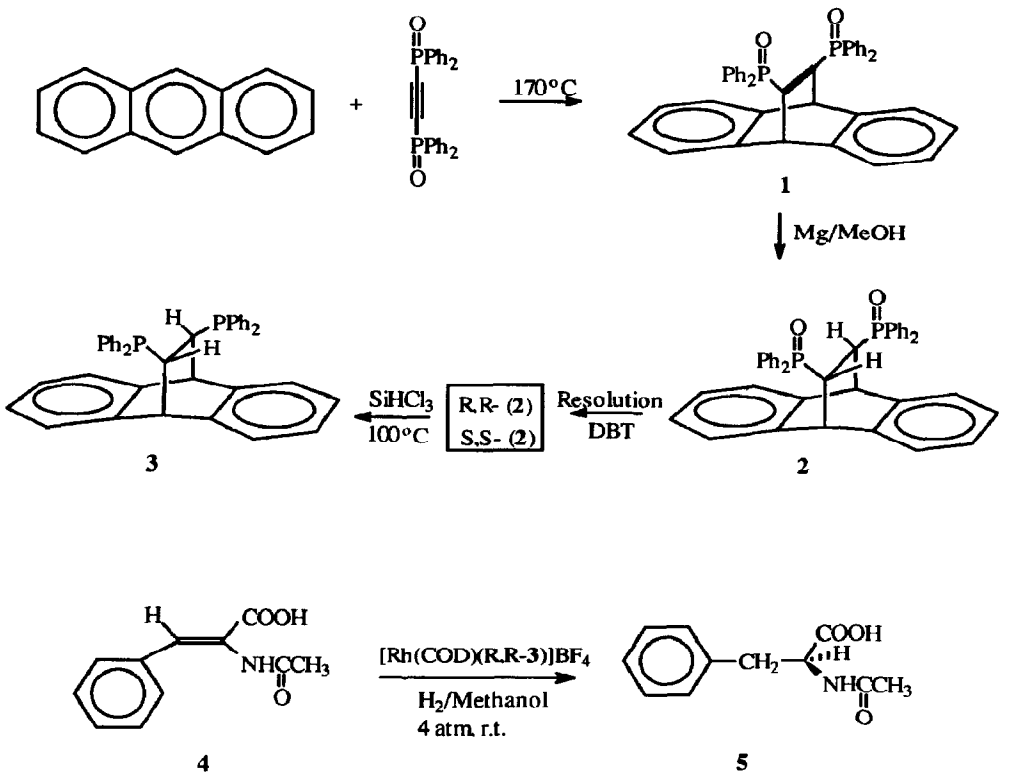
Abstract. Anthraphos (*trans*-9,10-dihydro-9,10-ethanoanthracene-11,12-bis(diphenylphosphine) (**3**), a conformationally rigid, C_2-symmetric diphosphine, has been prepared in three steps, the key step being the Diels-Alder reaction between anthracene and ethyndiylbis(diphenylphosphine oxide). Resolution of anthraphos followed by formation of the [Rh(COD)(anthraphos)]BF_4 complex afforded an optically active hydrogenation catalyst precursor whose crystal and molecular structure and absolute configuration were determined by single crystal X-ray diffractometry. Use of the (*R,R*)-(-) form of the catalyst precursor to hydrogenate (Z)-α-acetamidocinnamic acid gave (*S*)-(+)-N-acetylphenylalanine in 90% enantiomeric excess.

Optically active chelating diphosphines continue to attract a great deal of attention as ligands for homogeneous transition metal catalysts that can effect asymmetric hydrogenations and other enantioselective catalytic processes.[1] Reactions of this type have been shown to be extremely useful, not only for laboratory preparations of enantiopure substances, but for industrial syntheses of pharmaceutical agents in optically pure form.[2] Optically active diphosphines and other chiral auxiliaries have been shown to be particularly effective in asymmetric inductions when they have C_2 symmetry,[3] and in the present communication, we report the facile preparation of a new, conformationally rigid, C_2-symmetric diphosphine, its resolution, the preparation and crystal structure of a rhodium^I complex and the use of this complex in a catalytic asymmetric hydrogenation reaction.

Anthraphos, *trans*-9,10-dihydro-9,10-ethanoanthracene-11,12-bis(diphenylphosphine) (**3**), was prepared as outlined in Scheme 1. Addition of ethyndiylbis(diphenylphosphine oxide)[4] to anthracene afforded the Diels-Alder adduct **1** (87%),[5] and reduction of this material with magnesium in methanol gave anthraphosdioxide (**2**) in a yield of 92%.[6] This material was resolved through the use of D- and L-dibenzoyltartaric acid (DBT) according to the procedure of Brunner and Pröbster.[7] In this way, 1.8 g of optically pure (-) and 1.5 g of optically pure (+)-anthraphosdioxide were obtained from 4.3 g of the racemate. Treatment of (-)-anthraphosdioxide, $[\alpha]_D$ = - 34° (c = 2.0, methanol), with trichlorosilane in anhydrous benzene[7b] afforded (+)-anthraphos, mp 157-158°,$[\alpha]_D$ = + 109° (c = 1.0, $CHCl_3$), in 76% yield after recrystallization from an ether/pet ether mixture. Anthraphos appears

to be stable indefinitely in the solid state, but is converted slowly to its oxides in non-deoxygenated solutions.

Scheme 1



Reaction of (+)-anthraphos with $[Rh(COD)Cl]_2$ followed by addition of $NaBF_4$ afforded an 80% yield of crystalline (-)-$[Rh(COD)(anthraphos)]BF_4$, which decomposed at 250 °C without melting and exhibited $[\alpha]_D$ = -45° (c = 0.5, $CHCl_3$). The complex appears to be quite air-stable, showing no change in its ^{31}P NMR spectrum over 4 days in $CDCl_3$. The complex could be recrystallized from methanol, depositing beautiful orange-red bipyramids that were subjected to room temperature X-ray diffraction analysis (MoKα), space group $P4_1$, a = 10.200(7) Å, c = 39.97(5) Å, V = 4158(3) $Å^3$, Z = 4, D_{calc} = 1.394 g/cm^3, R = 6.44%, absolute configuration (R,R).[8] An ORTEP diagram of the complex is shown in Figure 1.

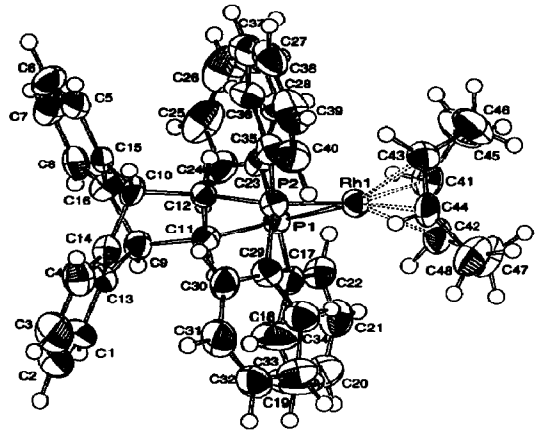


Figure 1. ORTEP diagram of catalyst precursor (*R,R*)-(-)-[Rh(COD)(anthraphos)]BF_4. The BF_4^- counterion has been omitted for clarity.

It is interesting to compare the structure of the anthraphos complex of Figure 1 with the crystal structures of the rhodium^I complexes of two well known chiral diphosphines, norphos (2-*exo*-3-*endo*-bis(diphenylphosphino)bicyclo[2.2.1]heptene)[9] and chiraphos ((2*S*,3*S*)- or (2*R*,3*R*)-bis(diphenylphosphino)butane).[10] In the anthraphos complex, the P1-C11-C12-P2 dihedral angle of the five-membered chelate ring is 61°, which is between that of norphos (64°) and chiraphos (52°), but closer to the former. Similarly, the P-Rh bond lengths in the anthraphos complex (2.31 and 2.29 Å) lie between those of norphos (2.32 and 2.32 Å) and chiraphos (2.28 and 2.27 Å), and the C-P-Rh angles are anthraphos, 105 and 106°; norphos, 103 and 104°; and chiraphos, 110 and 110°. The chelate ring of the Rh^I anthraphos complex is, therefore, somewhat less strained than that of the norphos complex, a finding that presumably reflects the slightly greater flexibility of the bicyclo[2.2.2]octadiene carbocyclic ring system of anthraphos compared to the bicyclo[2.2.1]heptene framework in norphos.

The chelate ring of (*R,R*)-(-)-[Rh(COD)(anthraphos)]BF_4 adopts the λ conformation, which is predicted to lead to products of (*S*) absolute configuration upon catalytic hydrogenation of α-N-acylaminoacrylic acids.[11] To test this, and to determine the efficacy of the catalyst, a hydrogenation of (Z)-α-acetamidocinnamic acid (4) was carried out at room temperature in methanol.[12] This afforded a quantitative yield of N-acetylphenylalanine (5) with a non-optimized enantiomeric excess of 90% (*S*)-(+) as determined by chiral HPLC analysis of the methyl ester (baseline separation with a Chiralcel OD column[13]). This ee is comparable to that obtained by using chiraphos (89%)[14] and somewhat less than that obtained with norphos (96%).[15]

In principle, by reacting substituted anthracenes and other arenes with ethyndiyl-bis(diphenylphosphine oxide), a host of potentially useful optically active diphosphines can be prepared. Experiments along these lines are currently under way in our laboratory.

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References and Footnotes

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12. 60 mL Schlenk tube; 10 mL MeOH; 0.49 g substrate; 2.1 mg of catalyst precursor (mole ratio of substrate to catalyst =1000); initial hydrogen pressure ca. 4 atm; 18 h at room temperature.
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