

Palladium on Carbon

[7440-05-3] · Pd · Palladium on Carbon · (MW 106.42)

(catalyst for hydrogenation of alkenes, alkynes, ketones, nitriles, imines, azides, nitro groups, benzenoid and heterocyclic aromatics; used for hydrogenolysis of cyclopropanes, benzyl derivatives, epoxides, hydrazines, and halides; used to dehydrogenate aromatics and deformylate aldehydes)

Solubility: insol all organic solvents and aqueous acidic media.

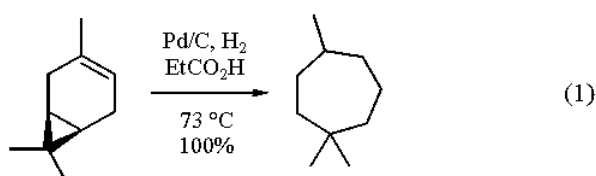
Form Supplied in: black powder or pellets containing 0.5-30 wt % of Pd (typically 5 wt %); can be either dry or moist (50 wt % of H₂O).

Analysis of Reagent Purity: atomic absorption.

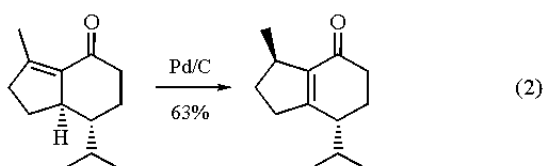
Handling, Storage, and Precautions: can be stored safely in a closed container under air but away from solvents and potential poisons such as sulfur- and phosphorus-containing compounds. Pyrophoric in the presence of solvents. General precautions for handling hydrogenation catalysts should be followed. The catalyst must be suspended in the organic solvent under an atmosphere of N₂. During filtration the filter cake must not be allowed to go dry. If a filter aid is necessary, a cellulose-based material should be used if catalyst recovery is desired.

Hydrogenation and Hydrogenolysis: Carbon-Carbon Bonds.

The use of Pd/C for the selective reduction of alkynes to alkenes is generally not satisfactory, but a few examples have been reported. For example, the Pd/C-catalyzed reduction of 3,6-dimethyl-4-octyne-3,6-diol gave the enediol in 98% yield after absorption of 1 mol of H₂.¹ Further reduction gave the diol in 99% yield. Pd on other supports, such as Pd/CaCO₃ and Pd/BaCO₃, are much more effective for this conversion. Pd/C is usually used for the complete saturation of alkynes and alkenes to their corresponding hydrocarbons.² In some instances, isomerization of the double bond during hydrogenation occurs before reduction, which leads to unexpected results. For example, reduction of car-3-ene gave the cycloheptane with Pd/C instead of the expected cyclohexane derivative (eq 1).³

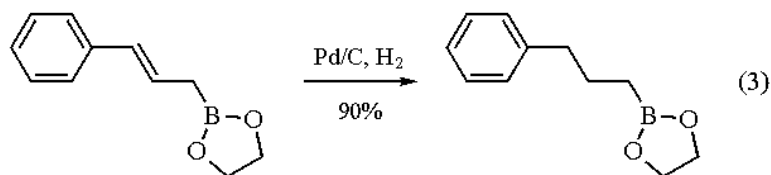


Isomerization of a double bond from one position to a hydrogenation inaccessible location has also been observed (eq 2).⁴

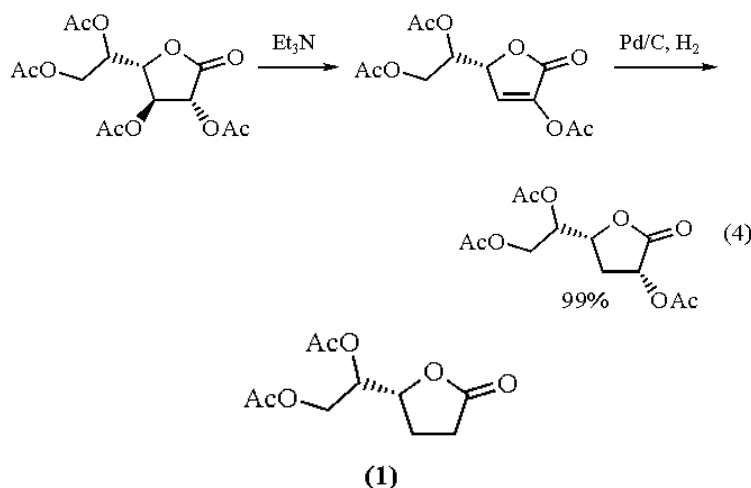


Next to the reduction of nitro groups, double and triple bonds are generally the next easiest functional groups to undergo hydrogenation. Some less reactive functional groups include ketones,⁵ esters,⁶ benzyl ethers,⁷ epoxides,⁸ and N-O bonds.⁹ These remain intact under conditions needed to reduce alkenes and alkynes. Under longer reaction times and/or more forcing conditions, some of these functional groups will

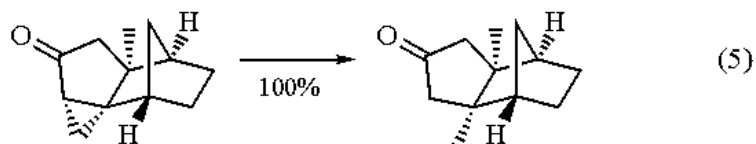
also be affected. Allylboron compounds can be hydrogenated to the propylboron derivatives, the C-B bond remaining intact (eq 3).¹⁰



Treatment of acylated aldonolactones with hydrogen in the presence of Pd/C and triethylamine provided 3-deoxyaldonolactones in excellent yields (eq 4).¹¹ The α,β -unsaturated intermediate was hydrogenated stereospecifically to give the product. Substituting Pd with Pt catalysts gave the 2-acetoxy hydrogenolyzed product (1) instead. Hydrogenolysis of the acetate preceded the double bond hydrogenation.

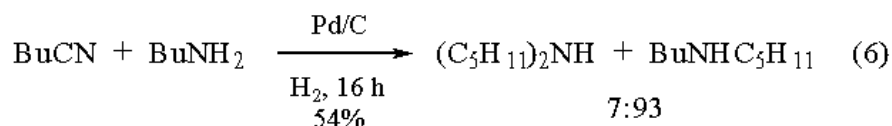


Hydrogenolysis of C-C bonds using Pd/C is mainly limited to cyclopropane opening. The less substituted and electronically activated bond cleavage is preferred. An example is shown in (eq 5).¹²

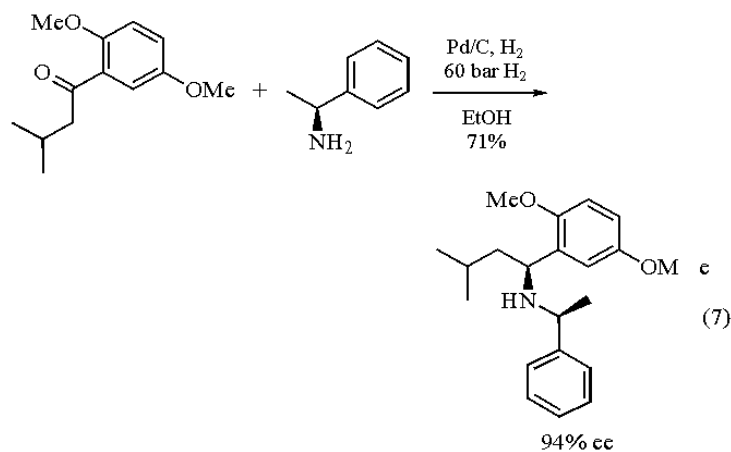


Carbon-Nitrogen Bonds

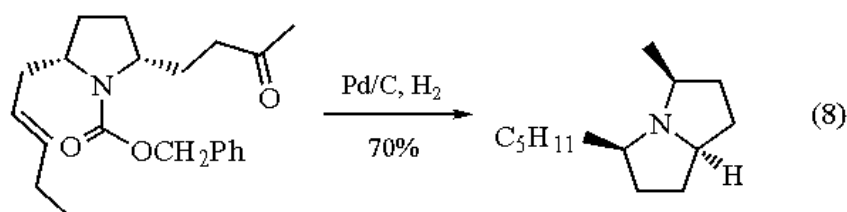
The hydrogenation of nitriles to primary amines is best accomplished with Pd/C in acidic media or in the presence of ammonia. In the absence of acid or ammonia, a mixture of primary and secondary amines is observed. This effect was taken advantage of and mixed secondary amines were obtained selectively by the reduction of a nitrile in the presence of a different amine (eq 6).¹³ Hydrogenation in aqueous acidic conditions can lead to aldehydes and/or alcohols.¹⁴



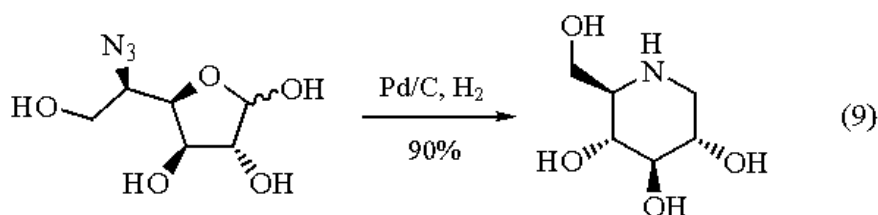
Reductive alkylation is a convenient and efficient way of obtaining secondary and tertiary amines.¹⁵ *N,N*-Dimethyl tertiary amines can be obtained from both aromatic and aliphatic primary amines or their precursors. Using α -methylbenzylamine as the chiral auxiliary, highly diastereoselective reduction of the intermediate imine has been observed (eq 7).¹⁶



This method also provides a convenient route to nitrogen containing heterocycles. Hydrogenolysis of the Cbz group followed by an in situ reductive alkylation process gave a bicyclic heterocycle (eq 8).¹⁷ The alkene was also reduced.

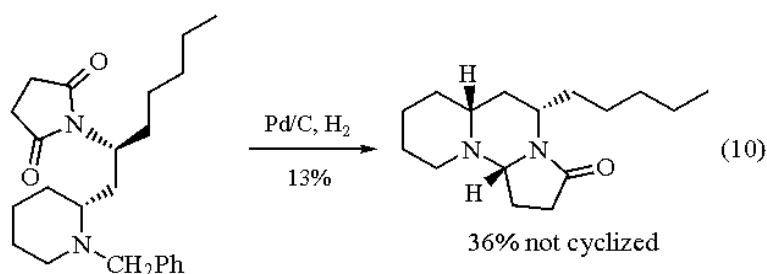


Other amine precursors, such as azides, can be utilized in the reductive alkylation reaction. For example, a furanose ring was opened and reclosed to form a piperidine ring system (eq 9).¹⁸ A pyranil azide similarly provided the seven-membered nitrogen heterocycle.



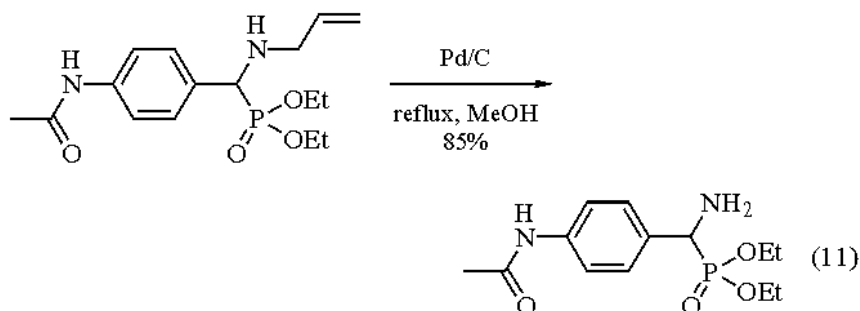
Similar to nitriles, hydrogenation of oximes is best carried out under acidic conditions to minimize secondary amine formation.¹⁹

Benzylic amines can be readily hydrogenolyzed to give less alkylated amines.²⁰ The C-N bond can be cleaved under both transfer hydrogenation²¹ and regular hydrogenation conditions.²² In many cases the newly debenzylated amines can further react, resulting in more structurally complex products (eq 10).²³

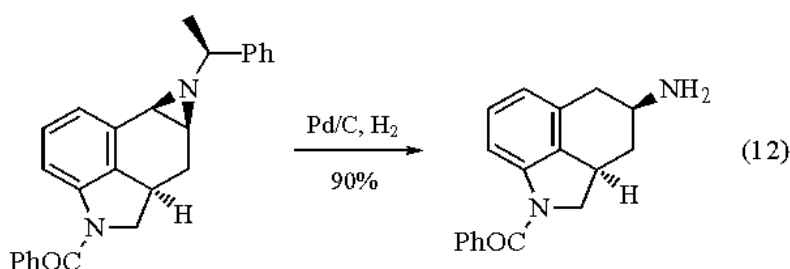


The heterogeneous catalytic debenzylation of *N*-benzylated amides with Pd/C is generally a difficult process and should not be considered in a synthetic scheme.

Allylamines have also been deallylated using Pd/C catalysis (eq 11).²⁴



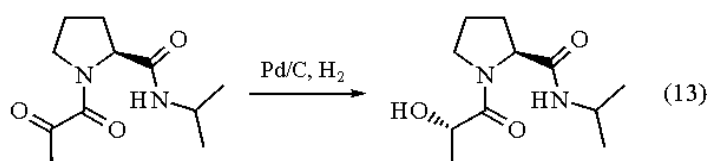
Aziridines are hydrogenolyzed to give ring-opened amines. In eq 12, the more reactive benzylic C-N bond was cleaved selectively.²⁵



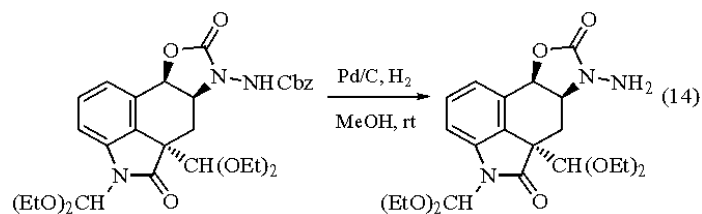
Carbon-Oxygen Bonds

Pd/C is best suited for the hydrogenation and hydrogenolysis of benzylic ketones and aldehydes. The reduction of dialkyl ketones to the alcohols is more sluggish and further hydrogenolysis to the alkane is even slower.²⁶ The hydrogenation of benzylic ketones (aryl alkyl and diaryl ketones) to alcohols is a very facile process with Pd/C.²⁷ Further hydrogenolysis of the benzylic alcohols to the alkane products can be a major problem with Pd/C catalysts, but can be controlled.²⁸ In general, aryl ketones and aldehydes can be reduced to alcohols under neutral conditions or in the presence of an amino functional group or an added amine base.²⁹ In the presence of acids, hydrogenolysis is more prone to occur. Using other catalysts such as *Platinum on Carbon* Ru/C, Rh/C and *Raney Nickel*, is an alternative.

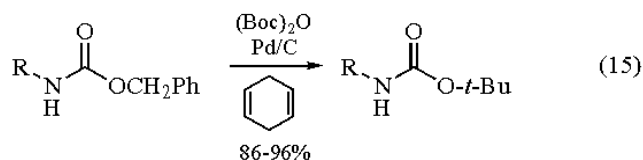
Trifluoromethyl ketones are reduced to alcohols without dehalogenation or further hydrogenolysis.³⁰ The hydrogenation of a chiral proline derivative provided the α -hydroxyamide product in 77% de and 100% yield (eq 13).³¹



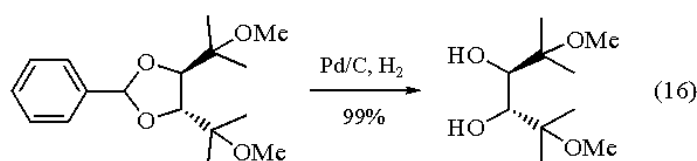
Hydrogenolysis of a benzyl group attached to an oxygen atom is a common step in complex synthetic schemes. Benzyl esters,³² benzyl carbamates,³³ and benzyl ethers³⁴ are readily hydrogenolyzed to acids, amines, and alcohols, respectively. *N*-Oxides protected as the benzyl ethers can be deprotected without hydrogenolysis of the N-O bond.³⁵ Hydrazines protected with benzyloxycarbonyl (Cbz) groups have been deprotected without N-N bond cleavage or the hydrogenolysis of benzylic C-O bonds (eq 14).³⁶



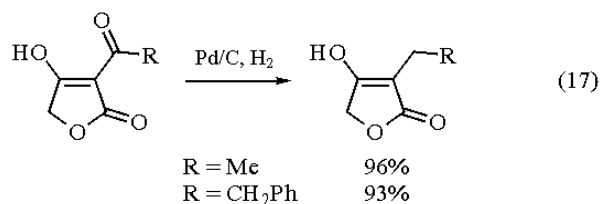
Benzyl carbamates have been transformed into *t*-butyl carbamates under transfer-hydrogenolysis conditions, but high catalyst loading was needed (eq 15).³⁷ A benzyl ether function survived these reaction conditions but a 1-alkene was saturated.



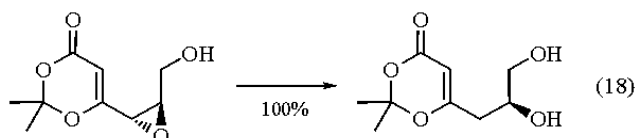
1,2-Diols protected as the acetal of benzaldehyde were deprotected under hydrogenolysis conditions (eq 16).³⁸



3-Acyltetronic acids were easily hydrogenolyzed to 3-alkyltetronic acids. Further reduction of the enol was not observed under the reaction conditions (eq 17).³⁹

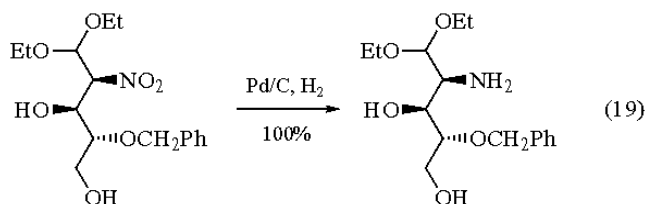


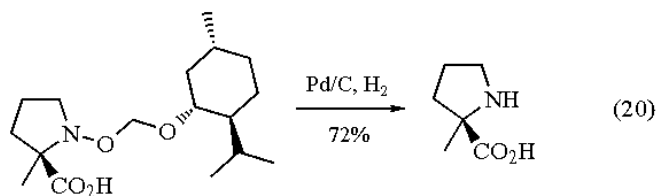
The C-O bond of epoxides can be hydrogenolyzed to give alcohols. Regioselective epoxide ring opening has been observed in some cases (eq 18).⁴⁰



Nitrogen-Oxygen Bonds

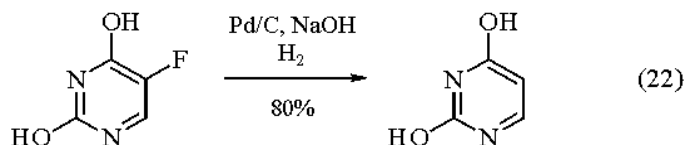
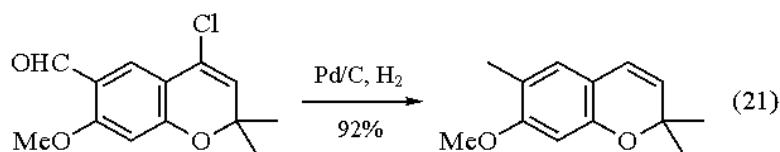
Both aliphatic and aromatic nitro groups are reduced to the corresponding amines (eq 19).⁴¹ N-O bonds are also readily hydrogenolyzed using Pd/C (eq 20).^{42a}





Carbon-Halogen Bonds.

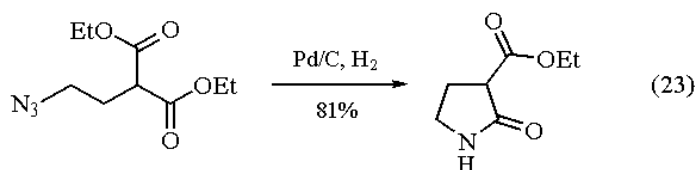
Aromatic halides (Cl, Br, I) are readily hydrogenolyzed with Pd/C.⁴³ The reaction generally requires the presence of a base to neutralize the acid formed. In the absence of an acid neutralizer, dehalogenation is slower and may stop short of completion. Vinyl halides are also dehalogenated but concomitant saturation of the alkene can also occur (eq 21).^{44a} Defluorination is a very slow process but one case has been reported (eq 22).⁴⁵



Selective dehalogenation of acyl halides can also be carried out with Pd/C and H₂ in the presence of an amine base to give aldehydes. This type of dehalogenation is commonly known as Rosenmund reduction (see *Palladium on Barium Sulfate*).⁴⁶

Nitrogen-Nitrogen Bonds

Azides⁴⁷ and diazo⁴⁸ compounds can be reduced over Pd/C to give amines. These groups have also been used as latent amines which, when hydrogenolyzed, can react with amine-sensitive functional groups in the molecule to give other amine products (eq 23).^{47c}

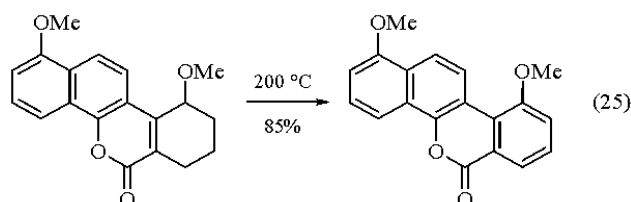
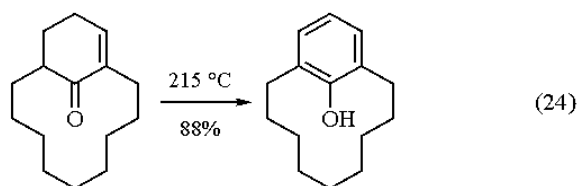


Carbocyclic and Heterocyclic Aromatics

Hydrogenation of carbocyclic aromatic compounds can be accomplished with Pd/C under a variety of reaction conditions.⁴⁹ The conditions are generally more vigorous than those used with Pt or Rh catalysts. Pyridine and pyridinium derivatives are hydrogenated readily to give piperidines.⁵⁰ Other heterocyclic aromatic ring systems such as furan,⁵¹ benzofuran,⁵² thiophene,⁵³ pyrrole,⁵⁴ indole,⁵⁵ quinoline,⁵⁶ pyrazine,⁵⁷ and pyrimidine⁵⁸ have also been hydrogenated over Pd/C.

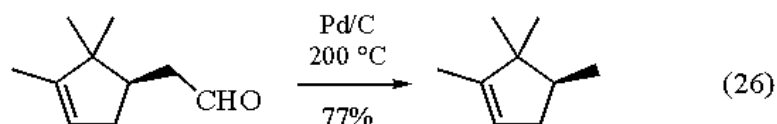
Dehydrogenation

At high temperatures, Pd/C is an effective dehydrogenation catalyst to provide carbocyclic and heterocyclic aromatic compounds.⁵⁹ An enone has been converted to a phenol (eq 24)^{59f} and a methoxycyclohexene derivative has provided an anisyl product (eq 25).^{59g}

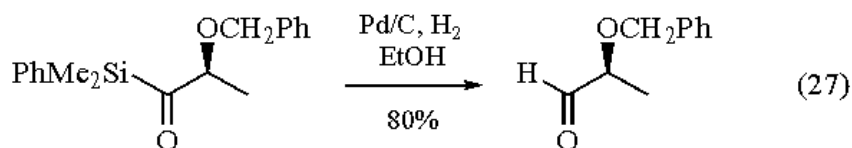


Miscellaneous Reactions

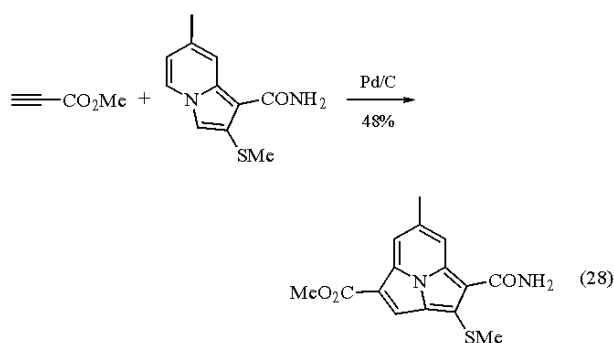
Decarbonylations can be carried out under the same conditions used for dehydrogenation (eq 26).⁶⁰ In this case, a trisubstituted alkene remained intact.



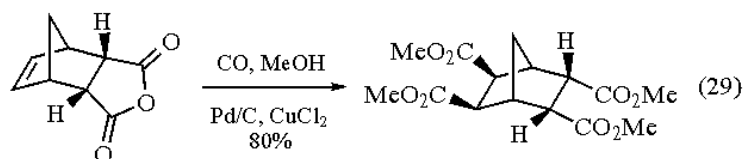
Reduction of an acylsilane gave an aldehyde without further hydrogenation to the alcohol or the hydrogenolysis of the benzyl ether (eq 27).⁶¹



Pd/C also catalyzed the cycloaddition reaction of an alkyne with a heterocycle to give a tricyclic heteroaromatic compound (eq 28).⁶²



In conjunction with *Copper(II) Chloride*, Pd/C catalyzed the biscarbonylation of norbornene derivatives (eq 29).⁶³ Norbornadiene itself was tetracarboxylated but in only 30% yield.



Related Reagents.

Palladium on Barium Sulfate, Palladium(II) Chloride, Palladium(II) Chloride-Copper(II) Chloride, Palladium-Graphite.

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