(s, 1 H), 6.80–7.00 (m, 4 H), 7.20–7.70 (m, 20 H).

Anal. Calcd for $C_{37}H_{28}S_2$: C, 82.8; H, 5.3. Found:[18] C, 81.3; H, 5.2.

For **21** (300 mg, 58%): mp 170–172 °C; FD mass spectrum, m/e 520 (M^+ for $C_{20}H_{16}OS$); NMR ($CDCl_3$) δ 2.05 (s, 3 H), 5.95 (s, 1 H), 6.55 (m, 2 H), 6.70 (m, 2 H), 7.20–7.80 (m, 20 H).

Anal. Calcd for $C_{37}H_{28}OS$: C, 85.4; H, 5.4. Found: C, 85.0; H, 5.4.

2,2′,6,6′-Tetraphenyl-4,4′-(propane-1,2-diylidene)bis[4*H*-pyran] (20). A mixture of 1.7 g (5 mmol) of 2,6-diphenylpyrylium perchlorate in 50 mL of dry THF was stirred under argon and chilled in a dry ice/acetone bath, and 2.6 mL (5 mmol) of 1.9 M sodium ethyl ethylphosphonate[19] was added. The mixture was stirred until a clear solution was obtained. To the solution was added 3.0 mL (5 mmol) of 1.6 M *n*-butyllithium. The solution was stirred for 5 min, and 1.4 g (5 mmol) of 2,6-diphenyl-4-(1-formylethylidene)-4*H*-pyran was added, and the mixture was stirred while it warmed to room temperature. The mixture was allowed to stand overnight and evaporated to dryness, and the residue was dissolved in CH_2Cl_2 and passed through a short column of alumina eluted with CH_2Cl_2. The solvent was removed, and the residue was recrystallized from toluene, giving 0.85 g of **20**: mp 196–197 °C; FD mass spectrum, m/e 504 (M^+).

Anal. Calcd for $C_{37}H_{28}O_2$: C, 88.1; H, 5.6; S, 6.3. Found: C, 87.8, H, 5.3; S, 6.7.

Registry No. **3**, 517-45-3; **4**, 92762-56-6; **5**, 92786-66-8; **6**, 92762-57-7; **7**, 92762-58-8; **8**, 92762-59-9; **9**, 24258-21-7; **10**, 86393-16-0; **11**, 86393-17-1; **12**, 86393-23-9; **13**, 86393-19-3; **14**, 86393-24-0; **15**, 92762-60-2; **16**, 92762-61-3; **17**, 92762-62-4; **18**, 92762-63-5; **19**, 92762-65-7; **20**, 92762-64-6; **21**, 80160-67-4; **22**, 92762-68-0; CH_3Cl, 74-87-3; $Cu(ClO_4)_2$, 13370-18-8; $ClCH_2CH(OEt)_2$, 621-62-5; EtP(O)OEt(ONa), 34326-12-0; 7*H*-dibenzo[*c*,*h*]xanthen-7-one, 3264-24-2; 7-methyldibenzo[*c*,*h*]xanthylium perchlorate, 37399-98-7; 7-methylenedibenzo[*c*,*h*]-7*H*-xanthene, 92762-66-8; 2-naphthol, 135-19-3; 14-(chloromethyl)-14*H*-dibenzo[*a*,*j*]xanthene, 72138-26-2; diazabicyclononene, 3001-72-7; 14-[(1,5-diazabicyclo[4.3.0]non-5-enyl)methyl]-14*H*-dibenzo[*a*,*j*]xanthene perchlorate, 92762-70-4; 14-methylene-14*H*-dibenzo[*a*,*j*]xanthene, 6612-09-5; 14,14′-(1,2-ethylene)bisdibenzo[*a*,*j*]xanthylium perchlorate, 92762-72-6; 2,6-diphenyl-4-ethylthiopyrilium perchlorate, 86393-26-2; 2,6-diphenyl-4-ethylidene-4*H*-thiopyran, 21186-87-8; 4-benzyl-2,6-diphenylthiopyrilium perchlorate, 41786-21-4; 4-benzylidene-2,6-diphenyl-4*H*-thiopyran, 41786-16-7; 4-benzyl-2,6-diphenylpyrilium perchlorate, 1252-67-1; 4-benzylidene-2,6-diphenyl-4*H*-pyran, 1168-63-4; 2,6-diphenyl-4-(trimethylsilyl)-4*H*-thiopyran, 80160-61-8; 2,6-diphenyl-4-(1-formylethylidene)-4*H*-thiopyran, 92762-73-7; 2,6-diphenylpyrilium perchlorate, 3558-68-7; 2,6-diphenyl-4-(1-formylethylidene)-4*H*-pyran, 40564-75-8.

(18) Repeated attempts to obtain a satisfactory combustion analysis for **21** were unsuccessful.

(19) Commercially available from Organometallics Inc., East Hampstead, New Hamphire.

Novel $LiAlH_4$ Reduction Pathway. Reactions of 2,3-Dihydro-1*H*-imidazo[1,2-*b*]pyrazol-2-ones with $LiAlH_4$. Preparations of 2,3-Dihydro-1*H*-imidazo[1,2-*b*]pyrazoles and Side Products

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Received April 4, 1984

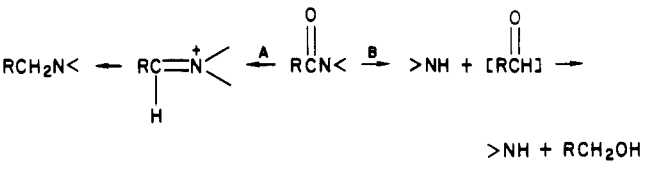
The direct $LiAlH_4$ reduction of 2,3-dihydro-1*H*-imidazo[1,2-*b*]pyrazol-2-ones, **2**, to 2,3-dihydro-1*H*-imidazo[1,2-*b*]pyrazoles, **10**, was unsuccessful. When the amide **2** had an *N*-phenyl substituent the reduction gave an *N*-carbonyl cleavage followed by carbonyl reduction to amino alcohols **6a–d**. When the amide **2** had *N*-methyl, *N*-*tert*-butyl, or *N*-2,6-dimethylphenyl as a substituent, then cleavage yielded an unusual formamide product, **9e–i**. Further $LiAlH_4$ treatment of **9e–h** gave **10e–h** by reductive ring closure of the iminium zwitterion **11e–f**, **14g**, or **14h** by addition of hydride to the intermediate **11g** or **11h** and/or carbonyl cleavage to **13e** or **13f**. $LiAlH_4$ treatment of **9i** gave only **13i**. Dehydrative ring closure of compounds **6a** and **6b** with P_2O_5 gave the products **10a** and **10b**.

The reduction of amides with lithium aluminum hydrides ($LiAlH_4$) is a frequently employed reaction. The most usual pathways are depicted in Scheme I. Path A involves the conversion of the amide to an iminium ion followed by the subsequent reduction of the iminium ion to the corresponding amine.[1] This is the most common pathway. The second pathway generally encountered[2] involves hydride attack on the carbonyl followed by the formation of aldehydic and amine moieties with the aldehydic portion being further reduced to alcohol (path B).

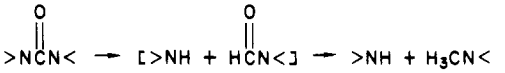
A slight variation on pathway B is encountered in the $LiAlH_4$ reduction of substituted ureas[3] where one still finds a carbonyl–nitrogen amide linkage cleavage (Scheme II) followed by reduction of the formyl group to a methyl.

In a previous paper we described a new synthesis of 2,3-dihydro-1*H*-imidazo[1,2-*b*]pyrazol-2-ones, **2**, by the

Scheme I



Scheme II



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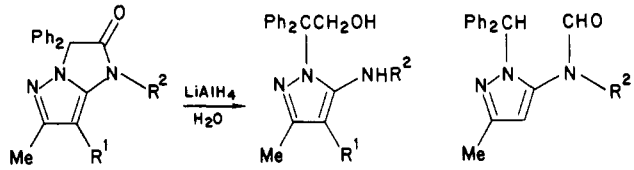
0022-3263/84/1949-4848$01.50/0

Table I. Reactions of 2,3-Dihydro-1*H*-imidazo[1,2-*b*]pyrazol-2-ones (2) with $LiAlH_4$. Isolated Yields and Melting Points of Compounds 6 and 9



2 6 9

compd[a]	R^1	R^2	reactn[b] time, h	yield, %	mp, °C
6a	Me	Ph	5	89	149–150
6b	Et	Ph	5	92	119–120
6c	Me	4-$MeOC_6H_4$	5	88	*c*
6d	Et	4-$CF_3C_6H_4$[g]	5	95	125–126
9e	Me	*t*-Bu	4[d]	92	124–125
9f	allyl	*t*-Bu	3[d]	88	*c*
9g	Me	Me	1[d,e]	90	167–168
9h	allyl	Me	1[d]	89	85–87
9i	Me	2,6-$Me_2C_6H_3$	2[d,f]	84	170–171

[a] Precise mass values agree to within ±0.003. [b] Conditions reported in Experimental Section. [c] Oil. [d] Reaction only at room temperature. [e] Reaction also undertaken under reflux for 15 h with identical results. [f] Reaction also undertaken under reflux for 11 h with identical results. [g] CF_3 group reduced to CH_3.

thermal rearrangement of 1-oxo-3,4,8-triaza-2,4,6,7-octatetraenes, **1**.[4] The antitumor[5,6,7] and medicinal[8,9,10,11] activity of the 2,3-dihydro-1*H*-imidazo[1,2-*b*]pyrazole, **10**, ring system has received considerable attention during the past years. We hoped for a direct conversion of **2** to **10** with $LiAlH_4$.

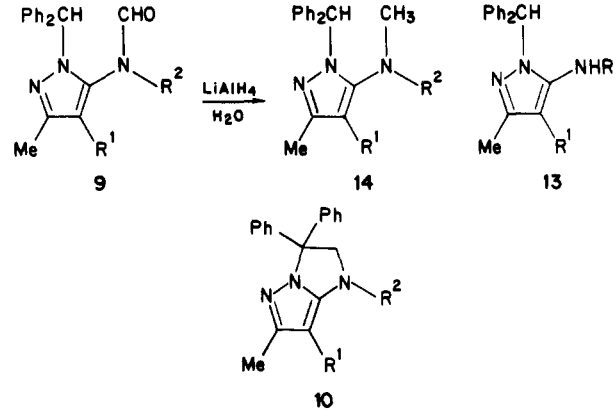
The $LiAlH_4$ reduction of **2** followed by hydrolysis gave **6** or **9** as shown in Table I. The mechanistic pathways proposed for the products of the reduction of **2** and **9** are depicted in Scheme III and are discussed below.

Reduction of Amide 2. Reduction of **2a–d** (R^2 = Ph or *p*-XC_6H_4) occurred via the known pathway B (Scheme I) giving the amino/carbonyl cleavage **3** → **7** (Scheme III). Spontaneous reduction of the carbonyl moieties to primary alcohol groups gave, after hydrolysis, the amino alcohols **6a–d**.

Reduction of **2e–h** (R^2 = alkyl) gave, what we believe to be the first examples of a carbonyl/α-carbon cleavage with $LiAlH_4$ to give isolated formamides, **9e–h**. This type of cleavage pathway, followed always by spontaneous reduction of the formamide carbonyl groups, has been observed[12] on the reduction of *N,N*-dimethyltriphenylacetamide to triphenylmethane and trimethylamine. None of the intermediate *N,N*-dimethylformamide was, however, observed in the above mentioned reaction.[12]

The major factors determining which pathway the reaction follows, either to give **6** or **9**, are undoubtedly the relative stabilities of the intermediates **7** vs. **4**. Where R^2 is aromatic both the pyrazole and the aromatic moieties

Table VI. Reduction of 1-(Diphenylmethyl)-3-methyl-5-(formylamino)pyrazole 9



9 14 13 10

	reactant 9		% products		
	R^1	R^2	14	13	10
9i	Me	2,6-$Me_2C_6H_3$	6	88	0
9e	Me	*t*-Bu	0	84	10
9f	allyl	*t*-Bu	0	78	16
9g	Me	Me	15	0	81
9h	allyl	Me	10	0	84

may provide stabilization for the *N*-pyrazole substituted anilide anion **7**. The relative stability of **7** and the unhindered nature of the N-carbon substituted formyl group on the 1-position of the pyrazole backbone allows the carbonyl moiety to be reduced to give **6** after hydrolysis.

If R^2 is alkyl the N substituted diphenylmethyl carbanion **4** has a greater stability than the anilide anion **7**. However, carbanion **4** is nucleophilic enough that the alkoxide **3** is essentially trapping **4** and preventing the less nucleophilic hydride from competing effectively to give **5**. On hydrolysis **3** is probably protonated to give **8** which collapses to **9**. An alternative pathway is that **4** is protonated to **9** directly forcing the complete shift of the **3** ⇄ **4** equilibrium toward **4** and thence to **9**.

Support for the aromatic pyrazole stabilization theory is found in the anamalous reduction reaction product for the *N*-2,6-dimethylphenyl substituted species **2i**. We presume that in this particular case the pyrazole backbone with substituents on the pyrazole 1- and 4-positions make it impossible to achieve planarity of the pyrazole and the 2,6-dimethylphenyl group in **7i** thus loses a significant amount of stabilization normally encountered in intermediate **7**. This fact evidently tips the balance in favor of **4** vs. **7** and forces the reduction of **2i** to go to **9i** not **6i**. Thus generally one may predict that the $LiAlH_4$ reduction of species of structure **2** will give **9** if R^2 is aromatic and **6** if R^2 is aliphatic.

Reduction of Formamide 5 (See Table VI). The only justification that we can find for the production of **13e,f,i** on $LiAlH_4$ reduction of the corresponding **9** is the relief of strain. Compound **13** is found as the exclusive reduction product of **9i** due to the relatively greater stabilization of the 2,6-dimethylanilide anion in comparison to the stabilization of the comparable *tert*-butylamide anion precursor to hydrolysis to **13e/13f** found on the reduction of **9e/9f** which also gives **10e/10f**, respectively.

The production of **10e–h** from the hydride reduction of **9e–h**, instead of **14e–h**, undoubtedly involves a competitive reaction favoring the carbanion attack on the iminium ion (**11** → **10**) rather than a hydride attack (**11** → **14**). This step also confirms the greater nucleophilicity of the N substituted diphenylmethyl carbanion vs. the hydride. The latter step (**11** → **14**) only occurs on the reduction of **9g/9h** which gives a small amount of **14g/14h** accompa-

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(6) Cory, J. G.; Fleischer, A. E. *Cancer Res.* **1980**, *40*, 3891.
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(9) Pilgrim, K. *J. Heterocycl. Chem.* **1980**, 17, 1413.
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(11) Schulze, W.; Willitzer, H. *Chem. Ber.* **1967**, *100*, 3460.
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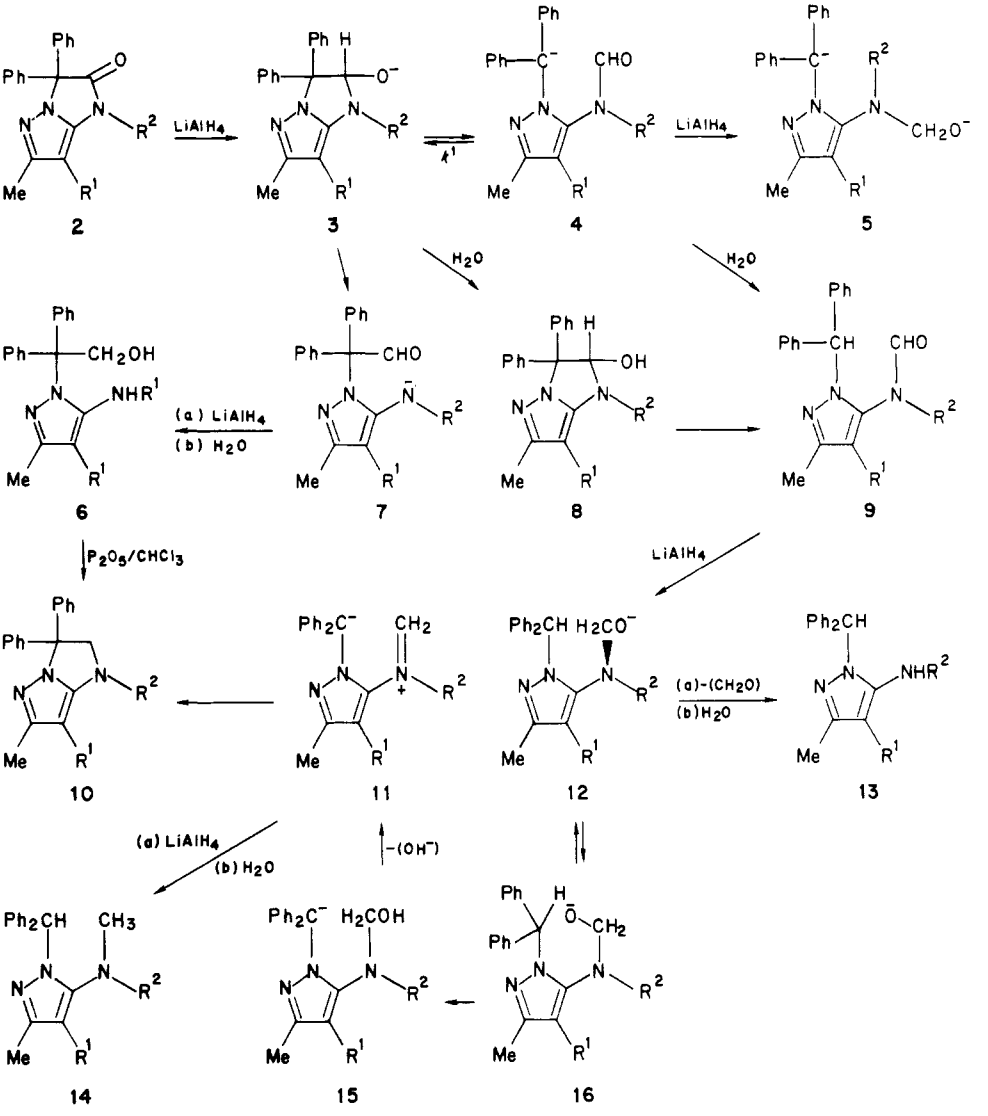
Scheme III



nying the major products **10g/10h**, respectively.

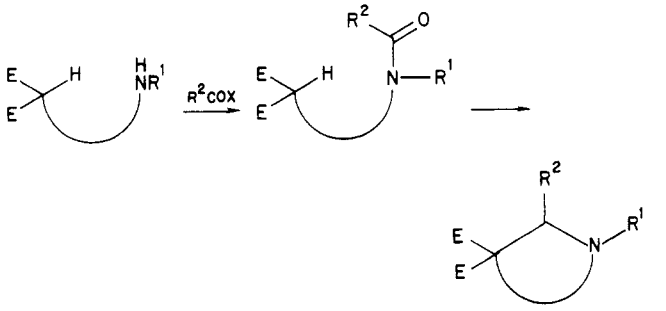
Support for the methine proton (Ph_2CH) abstraction (**16** → **15**, Scheme III) is found in the following observations: (a) when **13i** was followed to react with D_2O in a $DCCl_3$ solution in a NMR tube a NH → ND exchange was indicated by the disappearance of the NH peak at 4.62 ppm in the ^1H NMR spectrum. There was no change observed for the methine proton at 6.70 ppm. (b) When **13i** was allowed to react, under reflux, with a catalytic amount of sodium methoxide in deuterated methanol solvent both the NH and Ph_2CH protons, at 4.62 and 6.70 ppm, respectively, vanished. (c) When **9i** was reduced with $LiAlH_4$ followed by hydrolysis with D_2O only the secondary nitrogen in **13i** was found to be deuterated. (d) When **9g** was reduced as described in c, above, the compound **14g** produced was found to be deuterated on the methine carbon. These exeriments show that hydride is not basic enough to abstract the methine proton but the alkoxide **16** is.

This reductive ring closure reaction may be generalized as shown in Scheme IV and is being examined further.

Dehydrative ring closure of compounds **6a** and **6b** with P_2O_5[13] gave the desired product **10a** and **10b** in essentially quantitative yields.

(13) Elguero, J.; Knutsson, L.; Mignonac-Mondon, S. *Bull. Soc. Chim. Fr.* **1975**, *1-2* [Pt. 2], 255; *Chem. Abstr.* **1975**, *82*, 156174P.

Scheme IV[a]

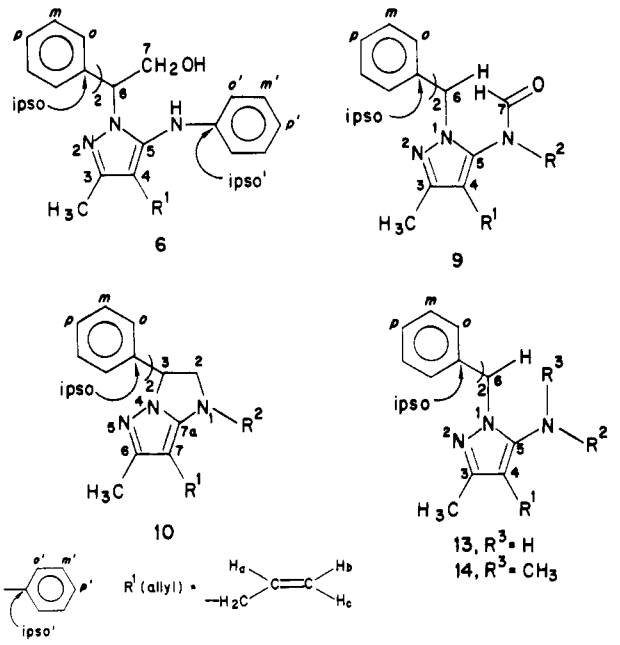


[a] E = electron-withdrawing group which is not affected by reducing agent.

Spectral Characteristics. Compounds **9** exhibit bands at 1695–1700 cm^{-1} (amide C=O) and 1580–1600 (pyrazole C=N/C=C) in their infrared spectra. Table II (see paragraph at end of paper about supplementary material) lists the characteristic infrared absorption frequencies of the pyrazole substituted formamide compounds **9**.

The ^1H NMR data for compounds **6** and **9** are collected in Table III (supplementary material). Compounds **6** show the NH peaks (3.87–4.02 ppm) and the OH peaks (5.66–5.79 ppm). The ^1H NMR show that compounds **9e,f,i** (R^2 = *t*-Bu or 2,6-$Me_2C_6H_3$) exist in two rotational conformation, cisoid and transoid, about the amide C–N

Chart I[a]



[a] The numbering systems used in the ^1H or ^{13}C NMR are as shown.

bond. This has been attributed[14] to the partial double bond character of the amide C–N bond. Observations of conformational preferences in unsymmetrically substituted *N,N*-dialkylformamides may be explained in terms of steric competition. It has been found[15,16] that the bulkier substituents tend to be cisoid to the formyl proton. Compounds **9g,h** however, are observed exclusively in one conformer. The major conformers show absorption at 6.03–6.45 (Ph_2CH) and 7.83–8.41 ppm (formyl proton). The minor conformers show absorption at 6.03–6.29 (Ph_2CH) and 8.23–8.85 ppm (formyl proton). The ratios[17] of the two conformers are as the follows: (a) Where R^1 = CH_3 and R^2 = *t*-Bu, 75/25. (b) Where R^1 = $CH_2CH{=}CH_2$ and R^2 = t-Bu, 80/20. (c) Where R^1 = CH_3 and R^2 = 2,6-$Me_2C_6H_3$, 75/25.

The ^{13}C NMR data for compounds **6** and **9** are collected in Table IV (supplementary material). Peaks at 138.3–140.0 (C3), 107.4–115.1 (C4), 146.0–146.5 (C5), 73.6–73.7 (C6), and 72.4–72.5 (C7) characterize the pyrazole substituted amino alcohols **6**. Again the ^{13}C NMR show that compounds **9e,f,i** exist in two rotational conformations. Compounds **9g,h** exist in one conformer. Peaks at 137.3–138.3 (C3), 108.3–114.8 (C4), 147.2–147.8 (C5), 63.9–64.4 (C6), and 161.6–163.6 (C7) characterize the pyrazole substituted formamide compounds **9**.

Table V (supplementary material) lists the mass spectral data. The compounds **6** showed the most intense ion [M – Ph_2CCH_2OH+1]$^+$ in EI mass spectra. The compounds **9** exhibited strong intensity of [Ph_2CH]$^+$, [M – PH_2CH]$^+$, and [M]$^+$ in that order in EI mass spectra. But a significant ion corresponding to the cleavage of the *tert*-butyl unit was detected for the *N*-(*tert*-butyl) compounds **9e** and **9f**.

Experimental Section

Melting points were obtained on a Thomas-Hoover Unimelt capillary apparatus and were uncorrected. IR spectra were recorded on a Unicap SP 1100 infrared spectrophotometer and calibrated by comparison with a standard polystyrene film sample. Precise mass spectra were recorded with DuPont 21-492B or DuPont CEC21-110D instruments with resolution 3300 or 5000. All analytical samples exhibited only one spot by TLC.

The ^1H and ^{13}C NMR spectra of approximately 10% (w/v) solutions in $CDCl_3$ were obtained on a Bruker Spectrospin Model WM 250. Chemical shifts are reported in parts per million (δ scale) vs. tetramethylsilane as an internal standard. In reporting the ^1H NMR data, the following abbreviations have been employed: coupling constant in hertz (J), singlet (s), broad singlet (bs), doublet (d), doublet of doublets (dd), triplet (t), quartet (q) and multiplet (m). The numbering systems used are shown in Chart I.

Dry nitrogen gas was routinely employed as the reaction atmosphere in all reactions. Tetrahydrofuran was dried and distilled from $LiAlH_4$. All glassware was baked at 150 °C for a minimum of 4 before use. Baker silica gel (60–200 mesh) and EM 7747 silica gel for column chromatography[18] was used throughout for product separation. Eastman chromagram precoated (silica gel on polyethylene) sheets impregnated with a fluorescent indicator were employed in thin-layer chromatographic operations.

2,3-Dihydro-1*H*-imidazo[1,2-*b*]pyrazol-2-ones (**2**) were prepared by the method of Schweizer and Lee.[4]

Reaction of Compounds 2a–d with $LiAlH_4$. Preparations of Compounds 6a–d. General Method. To a stirred solution of 2.0 mmol of the compound **2a–d** in 20 mL of THF was added $LiAlH_4$ (R^2 = Ph, 2.0 mmol, R^2 = $CH_3OC_6H_4$ or $CF_3C_6H_4$, 4.0 mmol) slowly. The mixture was stirred under reflux for 5 h. After cooling the reaction mixture, the excess hydride ion was destroyed with H_2O (0.25 mL) and a 15% NaOH solution (0.1 mL). The inorganic materials were filtered off, and the remaining solution was dried ($MgSO_4$) and concentrated in vacuo. Addition of ethanol or petroleum ether to the concentrated organic solution yielded **6a–d** as a solid. Recrystallization from ethanol (**6a,b**) or petroleum ether (**6d**) afforded a colorless analytical sample. Isolated yields (Table I), melting points (Table I), ^1H NMR (Table III), ^{13}C NMR (Table IV), and mass spectral data (Table V) were collected separately.

Reaction of Compounds 2e–i with $LiAlH_4$. Preparations of Compounds 9e–i. General Method. To a stirred solution of 2.0 mmol of the compound **2e–i** in 20 mL of THF was added $LiAlH_4$ (2.0 mmol) slowly. The mixture was stirred at either room temperature or under reflux for the amount time indicated in Table I and then the excess hydride was destroyed with H_2O (0.25 mL) and a 15% NaOH solution (0.1 mL). The inorganic materials were filtered off and the remaining solution was dried ($MgSO_4$) and concentrated in vacuo. Addition of ether/petroleum ether to the concentrated organic solution yielded **9e–2** as a solid. Recrystallization from ether/petroleum ether (**9e,g,h**) or ethanol (**9i**) afforded a colorless analytical sample. Isolated yields (Table I), melting points (Table I), IR (Table II), ^1H NMR (Table III), ^{13}C NMR (Table IV), and mass spectral data (Table V) were collected separately.

Dehydrative Ring Closure of Compound 6a with P_2O_5. Preparation of 6,7-Dimethyl-1,3,3-triphenyl-2,3-dihydro-1*H*-imidazo[1,2-*b*]pyrazole (10a). To a stirred solution of 1.0 g (2.6 mmol) of the compound **6a** in 20 mL of anhydrous chloroform was added 0.56 g (4.0 mmol) of P_2O_5 all at once. The chloroform solution was stirred under reflux gently for 3 h. At the end of that time the contents of the flask were cooled and the chloroform was decanted from the P_2O_5, extract with chloroform twice, washed once with 5% $NaHCO_3$ solution, and dried over anhydrous $MgSO_4$. Removal of the chloroform in vacuo yielded an oil from which **10a** (0.80 g, 84%) was crystallized from ethanol. Recrystallization from ethanol afforded a colorless analytical sample: mp 152–153 °C; ^1H NMR δ 1.88 (s, 3 H, C7 CH_3), 2.21 (s, 3 H, C6 CH_3), 4.80 (s, 2 H, C_2 H_2), 6.99–7.38 (m, 15 H, Ar); ^{13}C NMR δ 71.6 (C2), 70.8 (C3), 143.9 (C6), 93.0 (C7), 154.6 (C7a), 142.6 (ipso), 127.2 (*o*), 128.4 (*m*), 127.7 (*p*), 147.7 (ipso'), 119.4 (*o'*), 129.2 (*m'*), 122.7 (*p'*); mass spectrum, *m/z* (% base peak) 366 (39.7, M$^+$ + 1), 365 (100, M$^+$), 288 (13.0), 77 (12.5); precise mass calcd for $C_{25}H_{23}N_3$ 365.189, found 365.188.

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Dehydrative Ring Closure of 6b with P_2O_5. Preparation of 7-Ethyl-6-methyl-1,3,3-triphenyl-2,3-dihydro-1*H*-imidazo[1,2-*b*]pyrazole (10b). Compound **10b** (0.82 g, 83%) was prepared in the same manner as **10a** from 1.03 g (2.6 mmol) of **6b**: mp 89–90 °C; ^{1}H NMR δ 0.93 (t, J = 7.5, 3 H, CH_2CH_3), 2.23 (s, 3 H, C6 CH_3), 2.32 (q, J = 7.5, 2 H, CH_2CH_3), 4.77 (s, 2 H, C2 H_2), 6.98–7.37 (m, 15 H, Ar); ^{13}C NMR δ 71.9 (C2), 70.7 (C3), 144.2 (C6), 100.1 (C7), 153.9 (C7a), 142.5 (ispo), 127.1 (*o*), 128.3 (*m*), 127.6 (*p*), 147.5 (ispo'), 119.6 (*o'*), 129.2 (*m'*), 123.0 (*p'*); mass spectrum, m/z 380 (M^+ + 1), 379 (M^+), 182, 77; precise mass calcd for $C_{26}H_{25}N_3$ 379.205, found 379.207.

Reaction of Compound 9e with $LiAlH_4$. Preparation of 5-(*tert*-Butylamino)-3,4-dimethyl-1-(diphenylmethyl)pyrazole (13e) and 1-*tert*-Butyl-6,7-dimethyl-3,3-diphenyl-2,3-dihydro-1*H*-imidazo[1,2-*b*]pyrazole (10e). To a stirred solution of 0.72 g (2.0 mmol) of the compound **9e** in 15 mL of THF was added 0.08 g (2.0 mmol) of $LiAlH_4$ all at once. The mixture was stirred under reflux for 2 h. After cooling the reaction mixture, the excess hybride was destroyed with H_2O (0.25 mL) and a 15% NaOH solution (0.1 mL). The inorganic materials were filtered off, and the remaining solution was dried ($MgSO_4$). Thin-layer chromatography (TLC, 1:7 EtOAc–hexane, silica gel) showed the formation of two products. After removal of solvent in vacuo, the crude reaction mixture was chromatographed on a silica gel column eluting with EtOAc–hexane (1:7). This yielded the following in order of elution:

(a) **13e** (0.54 g, 84%) as an oil. Recrystallization from hexane afforded a colorless analytical sample: mp 110–111 °C; ^{1}H δ 1.14 (s, 9H, $C(CH_3)_3$), 1.91 (s, 3 H, C4 Ch_3), 2.16 (s, 3 H, C3 CH_3), 2.54 (s, 1 H, NH), 6.91 (s, 1 H, $CHPh_2$), 7.20–7.28 (m, 10 H, Ar); ^{13}C NMR δ 142.6 (C3), 108.2 (C4), 147.1 (C5), 62.4 (C6), 141.3 (ipso), 128.1 (*o*), 128.6 (*m*), 127.0 (*p*), 13.0 (C3 CH_3), 9.4 (C4 CH_3), 54.6 ($C(CH_3)_3$, 30.8 ($C(CH_3)$); mass spectrum, m/z 333 (M^+), 318, 277, 276, 168, 167, 166, 165, 152; precise mass calcd for $C_{22}H_{27}N_3$ 333.220, found 333.220. (b) **10e** (0.07 g, 10%) as an oil: ^{1}H NMR δ 1.29 (s, 9 H), $C(CH_3)_3$), 2.04 (s, 3 H, C7 CH_3), 2.16 (s, 3 H, C6 CH_3), 4.12 (s, 2 H, C2 H_2), 7.24–7.35 (m, 10 H, Ar); ^{13}C NMR δ 65.7 (C2), 69.2 (C3), 143.9 (C6), 92.2 (C7), 154.2 (C7a), 142.8 (ipso), 127.5 (*o*), 128.2 (m), 127.4 (*p*), 13.6 (C6 CH_3), 11.2 (C7 CH_3), 53.9 ($C(CH_3)_3$, 28.4 ($C(CH_3)_3$; mass spectrum, m/z (% base peak) 346 (64.7, M^+ + 1), 345 (76.2, M^+), 290(46.0), 289(30.7), 167(100), 165(55.9); precise mass calcd for $C_{23}H_{27}N_3$ 345.221, found 345.221.

Reaction of Compound 9f with $LiAlH_4$. Preparation of 5-(*tert*-Butylamino)-1-(diphenylmethyl)-3-methyl-4-(2-propenyl)pyrazole (13f) and 1-*tert*-Butyl-3,3-diphenyl-6-methyl-7-(2-propenyl)-2,3-dihydro-1*H*-imidazo[1,2-*b*]-pyrazole(10f). Compound **9f** (0.77 g, 2.0 mmol) was allowed to react as **9e** with 0.08 g (2.0 mmol) of $LiAlH_4$ for 3 h and the workup procedure was the same as **9e**. This yielded the following in order of elution:

(a) **13f** (0.56 g, 78%) as an oil. Recrystallization from hexane afforded a colorless analytical sample: mp 75–76 °C; ^{1}H NMR δ 1.26 (s, 9 H, $C(CH_3)_3$), 2.14 (s, 3 H, C3 CH_3), 2.60 (s, 1 H, NH), 3.14 (dd, J = 5.6 and J = 1.8, 2 H, $CH_2CH{=}CH_2$), 4.95 (dd, J = 17.1 and J = 1.8, 1 H, H_c), 5.02 (dd, J = 10.2 and J = 1.8, 1 H, Hb), 5.83 (m, 1 H, H_a), 6.91 (s, 1 H, $CHPh_2$), 7.23–7.28 (m, 10 H, Ar); ^{13}C NMR δ 143.1 (C3), 109.7 (C4), 147.5 (C5), 62.5 (C6), 141.1 (ipso), 128.1 (*o*), 128.5 (*m*), 127.0 (*p*), 13.2 (C2 CH_3), 28.1 ($CH_2CH{=}CH_2$), 136.5 ($CH_2CH{=}CH_2$), 114.9 ($CH_2CH{=}CH_2$), 54.2 ($C(CH_3)_3$), 30.8 ($C(ChH_3)_3$; mass spectrum, m/z 359 (M^3), 344, 303, 302, 168, 167, 166, 165, 152, 136; precise mass calcd for $C_{24}H_{29}N_3$ 359, 236, found 359.235.

(b) **10f** (0.12 g, 16%) as an oil. Recrystallization from hexane afforded a colorless analytical sample: mp 99–100 °C; ^{1}H NMR δ 1.26 (s, 9 H, $C(CH_3)_3$), 2.12 (s, 3 H, C6 CH_3), 3.25 (dd, J = 6.5 and J = 1.8, 2 H, $CH_2CH{=}CH_2$), 4.22 (s, 2 H, C2H_2), 4.93 (dd, J = 17.1 and J = 1.8, 1 H, H_c), 5.03 (dd, J = 10.1 and J = 1.9, 1 H, H_b), 5.90 (m, 1 H, H_a), 7.24–7.35 (m, 10 H, Ar); ^{13}C NMR δ 65.9 (C2), 69.3 (C3), 143.1 (C6), 94.6 (C7), 154.9 (C7a), 143.0 (ipso), 127.5 (*o*), 128.2 (*m*), 127.4 (*p*), 13.4 (C6CH_3), 28.8 ($CH_2CH{=}CH_2$), 136.8 ($CH_2CH{=}CH_2$), 115.0 ($CH_2CH{=}CH_2$), 54.2 ($C(CH_3)_3$), 28.2 ($C(CH_3)_3$; mass spectrum, m/z (% base peak) 372 (82.0, M^+ + 1), 371 (100, M^+), 315 (54.8), 314 (42.1), 239 (49.1), 167 (57.0), 165 (47.3); precise mass calcd for $C_{25}H_{29}N_3$ 371.236, found 371.233.

Reaction of Compound 9g with $LiAlH_4$. Preparation of 3,4-Dimethyl-5-(dimethylamino)-1-(diphenylmethyl)pyrazole (14g) and 3,3-Diphenyl-1,6,7-trimethyl-2,3-dihydro-1*H*-imidazo[1,2-*b*]pyrazole (10g). Compound **9g** (0.64 g, 2.0 mmol) was allowed to react as **9e** with 0.08 g (2.0 mmol) of $LiAlH_4$ for 3 h and the workup procedure was the same as **9e**. This yielded the following in order of elution:

(a) **14g** (0.09 g, 15%) as an oil: ^{1}H NMR δ 2.02 (s, 3 H, C4 CH_3), 2.12 (s, 3 H, C3 CH_3), 2.73 (s, 6 H, $N(CH_3)_2$), 6.89 (s, 1 H, $CHPh_2$), 7.19–7.30 (m, 10 H, Ar); ^{13}C NMR δ 138.9 (C3), 106.0 (C4), 147.1 (C5), 61.9 (C6), 141.1 (ipso), 128.2 (*o*), 128.6 (*m*), 127.1 (*p*), 12.5 (C3 CH_3), 8.3 (C4 CH_3), 43.8 ($N(CH_3)_2$); mass spectrum, m/z (% base peak) 306 (40.0, M^+ + 1) 305 (85.4, M^+), 304 (23.1), 168 (28.1), 167 (100), 166 (20.2), 165 (37.6), 152 (26.3), 138 (34.4); precise mass calcd for $C_{20}H_{23}N_3$ 305.189, found 305.189.

(b) **10g** (0.49 g, 81%) as an oil. Recrystallization from hexane afforded a colorless analytical sample: mp 107–108 °C; ^{1}H NMR δ 1.97 (s, 3 H, C7 CH_3), 2.18 (s, 3 H, C6 CH_3), 2.87 (s, 3 H, NCH_3), 4.10 (s, 2 H, C2 H_2), 7.23–7.36 (m, 10 H, Ar); ^{13}C NMR δ 72.0 (C2), 71.0 (C3), 142.4 (C6), 92.0 (C7), 153.8 (C7a), 142.4 (ipso), 127.2 (*o*), 128.3 (*m*), 127.5 (*p*), 13.1 (C6 ChH_3), 7.1 (C7 ChH_3), 37.9 (NCH_3); mass spectrum, m/z 304 (M^+ + 1), 303 (100, M^+), 226, 165, 77; precise mass calcd for $C_{20}H_{21}N_3$ 303.173, found 303.172.

Reaction of Compound 9h with $LiAlH_4$. Preparation of 5-(Dimethylamino)-1-(diphenylmethyl)-3-methyl-4-(2-propenyl)pyrazole (14h) and 1,6-Dimethyl-3,3-diphenyl-7-(2-propenyl)-2,3-dihydro-1*H*-imidazo[1,2-*b*]pyrazole (10h). Compound **9h** (0.69 g, 2.0 mmol) was allowed to react as **9e** with 0.08 g (2.0 mmol) of $LiAlH_4$ for 3 h and the workup procedure was the same as **9e**. This yielded the following in order of elution:

(a) **14h** (0.07 g, 10%) as an oil: ^{1}H NMR δ 2.10 (s, 3 H, C3 CH_3), 2.72 (s, 6 H, $N(CH_3)_2$), 3.22 (dd, J = 5.8 and J = 1.7, 2 H, $CH_2CH{=}CH_2$), 4.96 (dd, J = 16.9 and J = 1.8, 1 H, H_c), 5.00 (dd, J = 10.0 and J = 1.7, 1 H, H_b), 5.89 (m, 1 H, H_a), 6.88 (s, 1 H, $CHPh_2$), 7.19–7.30 (m, 10 H, Ar); ^{13}C NMR δ 137.3 (C3), 108.5 (C4), 147.3 (C5), 62.2 (C6), 141.2 (ipso), 128.2 (*o*), 128.7 (*m*), 127.2 (*p*), 12.6 (C3 CH_3), 27.8 ($CH_2CH{=}CH_2$), 137.3 ($CH_2CH{=}CH_2$), 114.6 ($CH_2CH{=}CH_2$), 44.1 ($N(CH_3)_2$, mass spectrum,[19] m/z 333, 332 (100, M^+ + H), 331, 330, 184, 169, 168, 167, 165.

(b) **10h** (0.58 g, 84%) as an oil: ^{1}H NMR δ 2.15 (s, 3 H, C6 CH_3), 2.82 (s, 3 H, NCH_3), 3.14 (dd, J = 5.5 and J = 1.8, 2 H, $CH_2CH{=}CH_2$), 4.11 (s, 2 H, C2H_2), 4.97 (dd, J = 16.5 and J = 1.8, 1 H, H_c), 5.00 (dd, J = 10.6 and J = 1.8, 1 H, H_b), 5.91 (m, 1 H, H_a), 7.26–7.35 (m, 10 H, Ar); ^{13}C NMR δ 71.9 (C2), 71.0 (C3), 142.3 (C6), 94.3 (C7), 153.8 (C7a), 142.3 (ipso), 127.1 (*o*), 128.3 (*m*), 127.5 (*p*), 13.0 (C6 CH_3), 26.5 ($CH_2CH{=}CH_2$), 137.5 (CH_2-$CH{=}CH_2$), 114.4 ($CH_2CH{=}CH_2$), 37.9 (NCH_3); mass spectrum, m/z 330 (64.9, M^+ + 1), 329 (100, M^+), 252 (31.4), 205 (33.9), 167 (46.8), 165 (59.5), 77 (51.8); precise mass calcd for $C_{22}H_{23}N_3$ 329.189, found 329.187.

Reaction of Compound 9i with $LiAlH_4$. Preparation of 3,4-Dimethyl-5-((2,6-dimethylphenyl)amino)-1-(diphenylmethyl)pyrazole (13i). To a stirred solution of 0.82 g (2.0 mmol) of the compound **9i** in 15 mL of THF was added 0.08 g (2.0 mmol) of $LiAlH_4$ all at once. The mixture was stirred at room temperature for 1 h and the excess hydride was destroyed with H_2O (0.25 mL) and a 15% NaOH solution (0.1 mL). The inorganic materials were filtered off, and the remaining solution was dried ($MgSO_4$). After removal of solvent in vacuo, the crude reaction mixture was chromatographed on a silica gel column eluting with EtOAc–hexane (1:7) to yield 0.67 (88%) of **13i** as a colorless solid. Recrystallization from hexane afforded an analytical sample: mp 98–99 °C; ^{1}H NMR δ 1.42 (s, 3 H, C4 CH_3), 1.97 (s, 6 H, 2,6-$(CH_3)_2Ph$), 2.12 (s, 3 H, C3 CH_3), 4.62 (s, 1 H, NH), 6.70 (s, 1 H, $CHPh_2$), 6.85–7.36 (m, 13 H, Ar); ^{13}C NMR δ 139.6 (C3), 104.7 (C4), 146.6 (C5), 64.2 (C6)8 140.0 (ipso), 128.4 (*o*), 128.6 (*m*), 127.5 (*p*), 129.0 (*o'*), 128.9 (*m'*), 122,6 (*p'*), 12.7 (C3 CH_3), 7.2 (C4 CH_3), 18.4 (2,6-$(CH_3)_2Ph$); mass spectrum, m/z 383 (100, M^+), 203, 199, 186, 167, 152; precise mass calcd for $C_{26}H_{29}N_3$ 383.236, found 383.235.

Acknowledgment. The generous support of the National Institute of General Medical Science (GM 27620)

(19) Precise mass value was not obtained due to no molecular ion in EI mass spectra.

is gratefully acknowledged. We would also like to thank Dr. Roger Crecely of the University of Delaware for obtaining and discussing the ^1H and ^{13}C NMR spectra, reported in this work, with us. Purchase of the Bruker WM 250 was supported, in part, by a grant (GM 27616) from the National Institutes of Health.

Registry No. **2a**, 89726-11-4; **2b**, 89726-13-6; **2c**, 92816-79-0; **2d**, 89726-36-3; **2e**, 89726-27-2; **2f**, 89726-29-4; **2g**, 89726-26-1; **2h**, 89726-28-3; **2i**, 89726-25-0; **6a**, 92816-80-3; **6b**, 92816-81-4; **6c**, 92816-82-5; **6d**, 92816-83-6; **9e**, 92816-84-7; **9f**, 92816-85-8; **9g**, 92816-86-9; **9h**, 92816-87-0; **9i**, 92816-88-1; **10f**, 92816-94-9; **10g**, 92816-95-0; **10h**, 92816-96-1; **13e**, 92816-92-7; **13f**, 92816-93-8; **13i**, 92816-91-6; **14g**, 92816-89-2; **14h**, 92816-90-5; $LiAlH_4$, 16853-85-3.

Supplementary Material Available: Full IR, ^1H and ^{13}C NMR, and mass spectral data for compounds **6** and **9** (6 pages). Ordering information is given on any current masthead page.

Heterogeneous Catalysis in Organic Chemistry. 3. Competitive Adsorption of Solvents during Alkene Hydrogenations[1]

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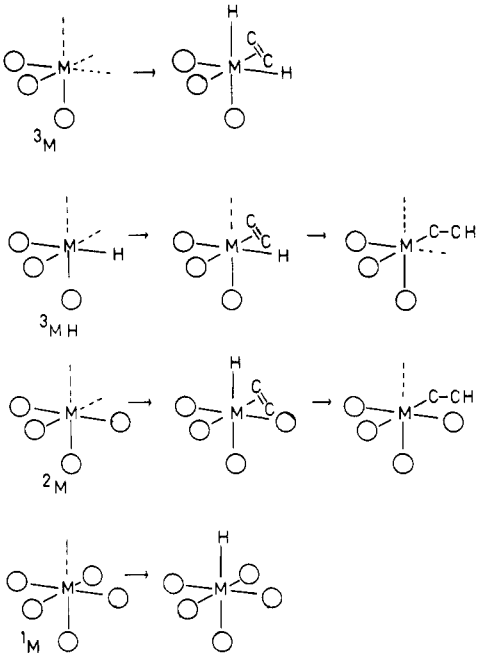
Received March 20, 1984

A single turnover reaction sequence has been used to determine the extent to which solvent can compete for adsorption sites in the hydrogenation of alkenes over Pt and Pd catalysts. Both methanol and ethanol are adsorbed readily on both Pt and active Pd catalysts converting the ^3M alkene saturation sites into ^2M isomerization sites and original ^2M sites into unreactive ^1M sites. *tert*-Butyl alcohol interacts only slightly with Pt catalysts presumably because of steric factors, but such restraints are not exhibited with Pd species. Over Pd the *tert*-butyl alcohol has adsorption characteristics similar to ethanol. 2-Propanol, on the other hand, enters into the reaction as a hydrogen donor in a transfer hydrogenation. THF and acetic acid are also adsorbed on the metal surface, but with THF there is little if any increase in isomerization, only a decrease in saturation capability. Acetic acid lies somewhere between THF and methanol. Other solvents such as ethyl acetate, ether, and acetone have little, if any, effect on catalyst activity.

Solvents are an important part of many heterogeneously catalyzed hydrogenations and, as such, their effect on the outcome of such reactions has been much discussed.[2-6] The solvent used in these reactions can effect their rate as well as influence the nature of the products obtained. The role of the solvent can be quite varied.[2] It can serve as a diluent to lessen the probability of interaction between molecules of reactive intermediates; it can serve as a reactant to trap intermediates and thereby prevent their further hydrogenation; it can prevent the product from precipitating onto the catalyst and deactivating it; or it can provide a medium in which a specific reaction and/or product stereochemistry is favored. In many of these cases the observed effects are due to the solvating ability of the solvent or its reactivity, dielectric constant, or acidity. Such cases are generally understood and the specific properties responsible are usually easily determined.

One aspect of the solvent effect in heterogeneously catalyzed reactions which has not been readily determinable is the nature of the solvent/catalyst interaction and the effect which this has on the outcome of the reaction.[5,6] In a study of the effect of the solvent on palladium-promoted alkene hydrogenation and isomerization, it was found that in an ethanol solvent the amount of double-bond isomerization observed was greater than that found by using a pentane solvent. To explain these results it was suggested that the ethanol was competing with hydrogen for adsorption on the active sites of the catalyst which decreased the amount of hydrogen present on the catalyst surface. This would diminish the extent of alkene saturation and increase the likelihood of isomerization.[6]

Scheme I



While this rational appeared reasonable and fit in with the classical Horiuti–Polanyi mechanism for olefin hydrogenation,[7] at that time there was no readily available means of directly determining its validity. However, the

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