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THE STEREOSELECTIVE CATHODIC REDUCTION OF EXO-CYCLIC DOUBLE BONDS

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The cathodic reduction of saturated cyclic ketones has been much studied and reaction conditions have been established for reduction to alcohols with both thermodynamic[1] and kinetic control[2] and, in acidic solution, for reduction to the corresponding methylene compound.[3] For reduction to alcohols only slight stereoselectivity in favour of the less stable epimer was achieved[2] and in all of the reductions the factors governing the stereochemical course of the reaction are poorly understood.

We have achieved highly stereoselective reductions of the double bonds in 1,1-dicyano-4-t-butylcyclohexylidene and 4-t-butycyclohexanone. A competing reaction, which is favoured in the case of menthone, is reduction in neutral solution to the corresponding hydrocarbon.

The experiments and results are summarised in the Table. Similar product mixtures are obtained from the reduction of 1,1-dicyano-4-t-butycyclohexylidene at mercury and vitreous carbon. The involvement of the surface in directing stereochemistry is therefore unlikely. In this reaction the less dissociating of the solvents used (EtOH) gives with lithium chloride better selectivity than with tetra-n-butylammonium iodide. By comparison sodium borohydride reduction, in DMF, gave among a mixture of products, the relevant axial : equatorial epimers in the ratio 22:78.

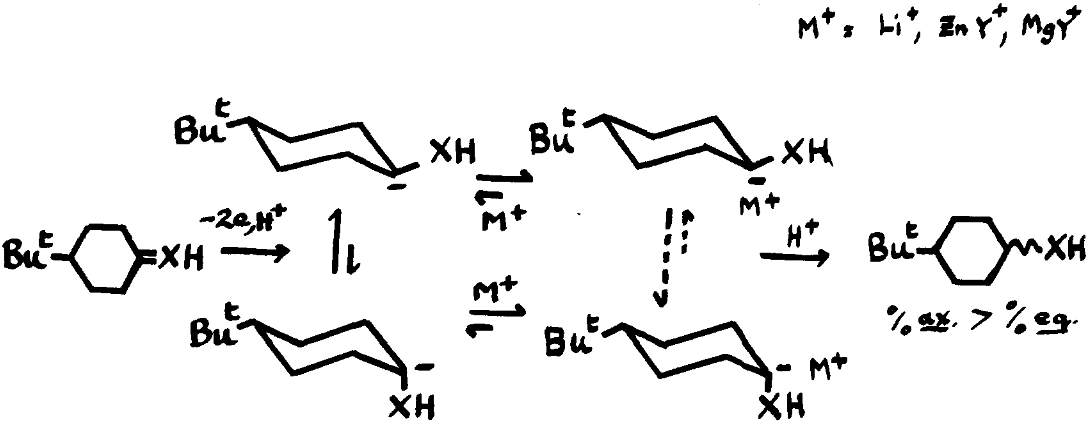
Table. Cathodic Hydrogenation of Exo-cyclic $>=O$ and $>=C(CN)_2$

Substrate (solvent-electrolyte-H^+donor)	Products, relative yields			
	ax. OH (%)	eq. OH (%)	Alkane (%)	curr. yield[a] (%)
1,1-Dicyano-4-t-butylcyclohexylidine[b]				
(DMF-TBAI-HOAc)	67	33	-	86
(EtOH-TBAI)	47	53	-	57
(EtOH-LiCl)	67	33	-	34
4-t-Butylcyclohexanone[c]				
(DMF-TBAI-HOAc)	15	77	8	37
(DMF-LiCl-HOAc)	23	70	7	47
(EtOH-TBAI-HOAc)	31	62	7	7
(EtOH-LiCl-HOAc)	42	54	4	48
(EtOH-LiCl-quinol)	42	56	2	83
(EtOH-$MgCl_2$ or $Mg(ClO_4)_2$-quinol)	>98	-	-	84
Menthone[d]				
(EtOH-TBAI-quinol)	5	31	64	15
(EtOH-$MgCl_2$-quinol)	10	-	90	27
(EtOH-$Zn(ClO_4)_2$-quinol)	-	-	100	39
(EtOH-LiCl-quinol)	10	29	61	57
(DMF-LiCl-quinol)	6	24	70	40

[a] Calculated for 2- or 4-electron reduction as relevant. [b] Divided cell, Hg cathode, substrate 0.06M, electrolyte 0.1M, HOAc 0.5M, 2F. mol^{-1} at constant current density (11 mA cm^{-2}). [c] Divided cell, Hg cathode, ketone 0.01M, electrolyte 0.1M, HOAc 0.05M, quinol 0.01M, 2F. mol^{-1} at constant current density (62.5mA cm^{-2}). [d] Divided cell, Hg cathode, menthone 0.01M, electrolyte 0.1M, quinol 0.01M, 2F. mol^{-1} at constant current density. (62.5mA cm^{-2}).

For 4-*t*-butycyclohexanone reduction virtually complete stereoselectivity is achieved using magnesium salt electrolyte and quinol, (which is for these reactions a more useful proton donor than acetic acid). Prior reduction of metal cation to form an amalgamated cathode does not appear to affect the course of the reaction since electro reduction in ethanol 0.01M in quinol at a Mg-Hg amalgam (1% w/w) in the presence of Bu_4NI or LiCl gave the stereochemical result characteristic of the added cation. Assuming the usual mechanism[4] the type of solvent and type of electrolyte necessary for reduction to the less stable epimer suggest a rationalisation in terms of ion-paired interactions (Scheme).

It has recently been suggested[5] that ion-pairing is important in directing the stereochemistry of cathodic pinacolisation of arylalkylketones. For such an explanation to apply to our reactions, rapid, ("non-Curtin-Hammett"), protonation must be supposed. This has good precedent in the interception of inversion at nitrogen.[6]



Some hindered ketones (dihydroisophorone, camphor) are not reduced significantly under the conditions given in the Table. However, camphor reduced cathodically with good current efficiency (50-75%) using "solvated-electron" conditions[2] to borneol (84%) and *iso*-borneol (16%). Menthone is reduced efficiently to menthane (also under conditions favouring ion-pair formation) and such reduction might constitute a useful alternative to chemical methods involving strongly acidic or alkaline conditions.

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