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THE STEREOSPECIFIC HYDROGENOLYSIS OF BENZYL DERIVATIVES.

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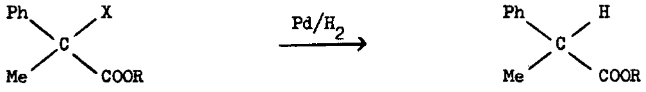
Catalytic hydrogenolysis of benzyl derivatives: $Ar-\overset{|}{\underset{|}{C}}-X \rightarrow Ar-\overset{|}{\underset{|}{C}}-H$, shows substantial stereospecificity. Racemisation is uncommon, and a mass of experimental data (1, 2, 3) correlate the steric result with both the electronegativity of the displaced group, and with the chemical nature of the catalyst metal:

	Retention	$>$	Inversion
Catalyst	Ni, Cu, Co	$>$	Pd
X	-OH, -OMe	$>$	-OAc, -OBz

At ruthenium hydrogenation of the aromatic ring is observed rather than hydrogenolysis (4), and this is also the case at nickel (1) when the substituent X = NH_2 and is difficult to remove. Catalytic displacement with inversion is of some interest, and the underlying correlation with the chemical nature of the catalyst metal, and of the displaced group, suggested a parallel with the hydrogenolysis of halides, where organo-metallic intermediates appear to be engaged (5). So as to obtain further information regarding the mechanism of the reaction we have examined the factors influencing the rate of hydrogenolysis.

Table 1 indicates the rate sequence: X = $-OH < -OAc < -O.CO.CF_3$ for a series of derivatives of atrolactic acid:



I

II

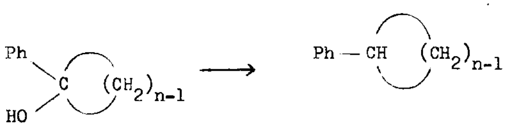
TABLE 1.

Hydrogen Uptake (c.c./min. x 10^{-2}) for 0.12M Solutions in the Solvent Indicated (5 c.c.) at Palladised Charcoal (75 mg.).

	Substance (I)		Product (II)	Solvent	Rate
R	X	$(\alpha)_D$	$(\alpha)_D$		
H	-OH	+ 48.3	+ 48.7	$HOAc/HClO_4$	7
H	-OAc	+ 6.1	- 6.5	EtOAc	5
H	$-O.CO.CF_3$	+ 4.9	- 9.7	EtOAc	v.fast
H	$-O.CO.CF_3$	+ 4.9	- 13.2	Hexane	40
Me	-OAc	- 36.1	+ 32.1	EtOAc	3.5
Me	$-O.CO.CF_3$	+ 4.5	- 22.5	Hexane	70

(+)- Atrolactic acid is configurationally related to (-)- hydratropic acid and the respective specific rotations, i.e. $(\alpha)_D$ 53.5° and $(\alpha)_D$ 51.8°, (6), indicate that at palladium hydrogenolysis occurs with a high degree of inversion. Acylation of atrolactic acid or its ester occurs with inversion of sign of rotation (2), and although many of these derivatives employed were less optically pure, a high degree of configurational inversion is evidently general.

The implication in Table 1 that the displacement of the lysed group, X, is rate limiting suggests that information relating to the reaction transition state might be derived from studying examples of the type:



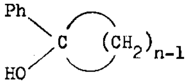
as n is varied. The results in Table 2 show a close similarity in the variation of rate with ring size to examples of solvolysis and of oxidative displacement in cyclic systems (7). The range of rate variation is, however, relatively much smaller than in comparable homogeneous reactions.

TABLE 2.

Hydrogen Uptake (c.c./min.) at Palladised Charcoal (60 mg.) in Alcohol (10 c.c.) for 1-phenyl-cycloalkanols (0.125M.), 

n	Rate	n	Rate
4	0.07	8	0.5
5	1.4		
6	0.6	$PhCH_2OH$	1.1
7	0.2	$PhCMe_2OH$	0.12

Since, however, the relative rates of hydrogenation of a series of cyclo alkanones (Table 3) follow the same sequence with ring size as the homogeneous reduction by sodium borohydride (8) it seems right to infer the relationships:

	hydrogenolysis	$sp^3 \longrightarrow sp^2$
	hydrogenation	$sp^2 \longrightarrow sp^3$

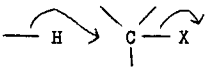
for the geometry of the rate limiting transition in these reactions.

TABLE 3.

Hydrogen Uptake (c.c./min. x 10^2) at Adams' Platinum Catalyst (20 mg.) for Cycloalkanones (3×10^{-2}M. in Ethyl Alcohol).

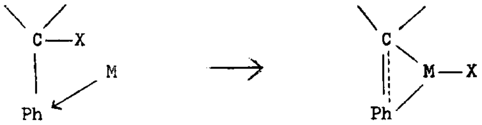
Cyclo -	Rate
butanone	7
pentanone	3.5
hexanone	5
heptanone	3
octanone	2.5

In considering the nature of hydrogenolysis with inversion we exclude first any mechanism of the kind:



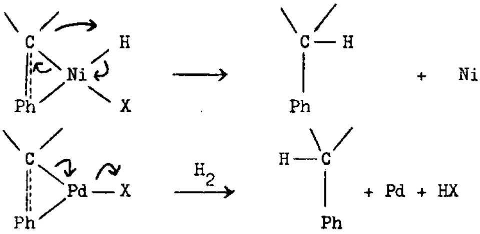
since such displacement at a tertiary carbon centre is sterically improbable, hydrogenolysis is rapid in a non-polar solvent, and typical hydride reagents do not hydrogenolyse benzyl derivatives. The alternative, i.e. that the displaced group is removed to give an intermediate which subsequently reacts with hydrogen is, however, consistent with the experimental data in Table 1 and 2.

Allyl derivatives of palladium, nickel and other metals are well known (9). Benzyl chromium is a known intermediate in chromous reduction of benzyl bromide (10). An analagous benzyl intermediate in hydrogenolysis:



which should be formed more easily as X becomes more electronegative and which involves rehybridisation in the direction: sp^3 → sp^2, is consistent with our results, and also permits hydrogen transfer with retention or inversion in different cases.

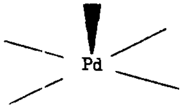
When racemisation can be prevented, the formation of a metal alkyl, and subsequent displacement at the metal alkyl bond is characterised by configurational retention (11). The displacement process (i) is therefore a wholly acceptable representation of the steric result of hydrogenolysis at nickel with retention.



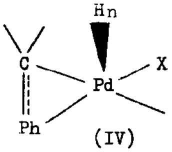
...... (i)

...... (ii)

The precedents in metal alkyl chemistry refer, however, to the more electropositive metals, e.g. Li or Mg, or to mercury alkyls under conditions where the cation will be stable. Palladium in hydrogen is readily reduced, and since hydrogenolysis is rapid the surface concentration of the benzyl intermediate could be high, and the hydrogen supply critical. Since hydrogenolysis at nickel is extremely slow the hydrogen concentration can scarcely become a limiting factor. At palladium therefore there are good reasons for considering an alternative polarisation of the metal alkyl bond as in (ii), leading to reaction with hydrogen in a type of nucleophilic substitution with inversion. The alternative modes of polarisation and reaction in (i) and (ii) clearly express the association of the steric result of hydrogenolysis with the chemical nature of the metal and of the lysed group. There remains the problem of hydrogen addition from above the adsorbed benzyl residue. Addition to an adsorbed molecule from above has been considered, and it has been suggested that residual p-orbitals may assist this process (12). We have elsewhere (5) proposed a catalyst model based on a co-ordination unit (III)



(III)



(IV)

which incorporates this concept and which adequately rationalises hydrogen transfer as in (IV) to an adsorbed benzyl residue with steric inversion; H_n = adsorbed hydrogen molecule (n = 2) or surface hydride (n = 1).

REFERENCES

1. W.A. Bonner, *J.Amer.Chem.Soc.*, 1952, **74**, 1024; W.A. Bonner, J.A. Zderic and G.A. Casaletto, *ibid.*, 1952, **74**, 5086; W.A. Bonner, and J.A. Zderic, *ibid.*, 1956, **78**, 3218.
2. S.Mitsui, and S. Imaizumi, *Bull.Soc.Chem., Japan*, 1961, **34**, 774; *idem.*, *ibid.*, 1963, **36**, 855; S. Mitsui, K. Konno, I. Onuma and K. Shimizu, *ibid.*, 1964, **85**, 437; S. Imaizumi, *Nippon Kagaku Zassi*, 1960, **81**, 627 and 631, through *Chem. Abs.*, 1962, **56**, 402.
3. S. Mitsui and Y. Kudo, *Chemistry & Industry*, 1965, 381.
4. S. Nishimura, *Bull.Chem.Soc. Japan*, 1959, **32**, 1155, through *Chem.Abs.*, 1960, 54, 19532.
5. D.A. Denton, F.J. McQuillin and P.L. Simpson, *J.Chem.Soc.*, 1964, 5535.
6. L. Smith, *J.Pract.Chem.*, 1911, **84**, 731; C.L. Arcus and J. Kenyon, *J.Chem.Soc.*, 1939, 916; E.L. Eliel and J.P. Freeman, *J.Amer.Chem.Soc.*, 1952, **74**, 923.
7. H.C. Brown, *J.Chem.Soc.*, 1956, 1248; F. Mares, J. Rocek, and J. Sicher, *Coll.Czech.Chem.Comm.*, 1961, **26**, 2355.
8. H.C. Brown and K. Ichikawa, *Tetrahedron*, 1957, **1**, 221.
9. Cf. G. Wilke, *Angew. Chem. (Eng.Edn.)*., 1963, **2**, 105.

10. Cf. F.A. Anet and E. Leblanc, J.Amer.Chem.Soc., 1957, 79, 2649; J.K. Kochi and D. Buchanan, ibid., 1965, 87, 859.

11. Cf. D.J. Cram, Fundamentals of Carbanion Chemistry, Academic Press, New York and London, 1965, p. 116 et. seq.

12. J.J. Rooney, F.G. Gault and C. Kemball, Proc.Chem.Soc., 1960, 407.