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THE HYDROGENOLYSIS OF SOME CYCLOPROPYL KETONES AND CYCLOPROPYL CARBINOLS WITH DIBORANE AND BORONTRIFLUORIDE

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A recent publication by Biswas, Houghton and Jackson (1) prompts us to report our results of a study concerning the reduction of some cylopropyl ketones and cyclopropyl carbinols with diborane in the presence and the absence of borontrifluoride.

In the course of our work on the homoallylic rearrangement of cyclopropyl carbinyl borates (2), we observed that p-anisyl cyclopropyl ketone is reduced by diborane to p-methoxy benzyl cyclopropane. Subsequently we noted, that the rate of this reduction showed remarkable variations when different batches of diborane solutions in tetrahydrofuran were used. Solution of BH_3 are usually prepared by adding BF_3 etherate to a mixture of $NaBH_4$ in diglyme, and by passing the diborane generated, with the aid of a stream of dry nitrogen, into tetrahydrofuran cooled to -20°. Therefore we assumed that along with the diborane traces of boronfluoride might also be carried over (3) and that different batches of BH_3/THF might be contaminated to a different extent with BF_3 which could catalyze the hydrogenolysis similarly to what is known of $AlCl_3$(4).

Testing this hypothesis we found that the addition of 10% (molar) boron trifluoride to the reaction mixtures indeed catalyzes hydrogenolysis in many other cases of cyclopropyl aryl ketones and cyclopropyl aryl methyl carbinols, all of which (with the exception of anisyl cyclopropyl ketone) exhibit normal behaviour in the presence of diborane at room temperature, or in refluxing tetrahydrofuran.

The typical procedure for these reductions was as follows: To 25 mmols of ketone or alcohol dissolved in 10 ml THF, and cooled to 0^{o}, 12.5 ml of a solution of diborane in tetrahydrofuran (2 molar in BH_3) was introduced by a hypodermic syringe. After one hour at room temperature, 0.31 ml BF_3 etherate (2.5 mmol) was added and stirring was continued at room temperature for a few hours.

The end of the reaction was usually indicated by the appearance of a white precipitate. After hydrolysis of the excess hydride, the products were isolated by the usual workup methods.

The results from these reactions are listed in Tables 1 and 2.

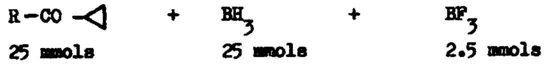
The structures of all compounds described in these tables have been confirmed by elemental analyses as well as by n.m.r. spectra. All the substituted benzyl cyclopropanes (Table 1) show the expected aromatic and cyclopropanic protons. The benzylic protons appear, in all three cases, as a doublet centered between δ2.46 - 2.55 (J=6.5 cps). Dicyclopropylmethane exhibits a triplet (2H) centered at δ1.26 (J=5.5) in addition to ten cyclopropanic protons. The 1-cyclopropylethyl benzenes (Table 2) show the methyl as a doublet at δ1.28-1.30 (J varies from 6.9 - 7.2 cps), the benzylic CH in the region δ1.6-2.2 as a multiplet in addition to the expected aromatic and cyclopropanic protons. 1,1-dicyclopropyl ethane shows the methyl as a doublet at δ0.98 (J=6 cps) in addition to the cyclopropylic and methine protons.
Similarly to our results Wechter reported (5) in 1963 that xanthone, thioxanthone and 9(10H)-acridone were reduced to the corresponding hydrocarbon by diborane, whereas 4,4'dimethoxy benzophenone gave only the corresponding alcohol.

While this work was underway Biswas, Houghton and Jackson reported (1) that electron rich aromatic ketones and aldehydes can be reduced to the corresponding substituted hydrocarbons by diborane, generated externally or internally. They found the internal method more potent, attributing this to the presence of both nucleophilic (BH_4^-) and electrophilic (BHX_2) species in the solution. In contrast to Wechter these authors found that 4,4'dimethoxy benzophenone is reduced to dianisylmethane both internally and externally.

For reasons not stated in their paper Biswas, Houghton and Jackson used 10 mols of $NaBH_4$ and

TABLE 1

The Reaction of Cyclopropyl Ketones with Diborane and Boron Fluoride



R−CO−◁ + BH_3 + BF_3

25 mmols 25 mmols 2.5 mmols

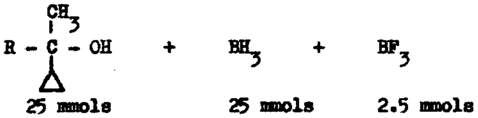
R	Product	Yield %	b.p.	n_D^{16}
C_6H_5-	C_6H_5-CH_2-◁	75	76°-80°/20 mm	1.5147
p-CH_3O-C_6H_4-	p-CH_3O-C_6H_4-CH_2-◁	70	120°-122°/25 mm	1.5247
p-Cl-C_6H_4	p-Cl-C_6H_4-CH_2-◁	72	112°-114°/25 mm	1.5321
▷—	▷- CH_2 -◁	≥ 80*	95°-97°/690 mm	1.4271
CH_3-	CH_3-CHOH-◁	quant.**	116°-118°/690	

* Yield was determined by gas chromatography. No alcohol was detected. Separation from tetrahydrofuran in good yield by distillation is difficult.

** Determined by gas chromatography.

TABLE 2

The Reaction of tert-Cyclopropyl Carbinols with Diborane and Boron Fluoride



$R-\overset{CH_3}{\underset{\triangle}{C}}-OH$ + BH_3 + BF_3

25 mmols 25 mmols 2.5 mmols

R	Yield of $R-\overset{CH_3}{\underset{\triangle}{C}}-H$ %	b.p.	n_D^{16}
C_6H_5-	75	86°-88°/25 mm	1.5123
p-Cl-C_6H_4-	79	118°-120°/25 mm	1.5274
p-CH_3O-C_6H_4-	68 *	126°-128°/25 mm	1.5193
▷-	60 **	100°-102°/690 mm	1.4326

* Starting material was found to be contaminated with 13% α-cyclopropyl p-methoxy styrene.

** Yield was estimated by gas chromatography. No starting material was detected in product. 20% 2,2-dicyclopropyl ethanol - presumably the product of elimination and hydroboration - was isolated from the residue after it was treated with alkaline H_2O_2.

20 mols of BF_3 for each mole of ketone. Since $NaBH_4$ reacts with BF_3 to give BH_3, in their internal reductions they eventually had 13.4 times the amount of BH_3 and sixty-six times the amount of BF_3 as compared with our reaction conditions. As to their external reductions, the diborane was generated by using the reagents in the same proportions as above, therefore, it seems plausible to us that in these conditions they also had relatively large excess of boron fluoride.

Table 3 lists some of our results from the reduction of various electron rich carbonyl compounds with diborane in the presence and absence of borontrifluoride. From this table it can be seen that 4,4'dimethoxy benzophenone is reduced by diborane to the corresponding alcohol, but the

TABLE 3

The Reaction of Diborane with Various Carbonyl Compounds in the Presence or Absence of Boron Fluoride

$$\underset{25\ \text{mmols}}{R - CO - R'} + \underset{25\ \text{mmols}}{BH_3} \longrightarrow$$

R -	R' -	BF_3 mmols	Products †
$4\text{-}CH_3O\text{-}C_6H_4\text{-}$	$C_6H_5\text{-}$	-	100% alcohol
$4\text{-}CH_3O\text{-}C_6H_4\text{-}$	$C_6H_5\text{-}$	2.5	31% alcohol 69% hydrocarbon
$4\text{-}CH_3O\text{-}C_6H_4\text{-}$	$4\text{-}CH_3O\text{-}C_6H_4\text{-}$	-	100% alcohol
$4\text{-}CH_3O\text{-}C_6H_4\text{-}$	$4\text{-}CH_3O\text{-}C_6H_4\text{-}$	2.5	100% hydrocarbon
$4\text{-}(CH_3)_2N\text{-}C_6H_4\text{-}$	H-	-	76% hydrocarbon
$4\text{-}(CH_3)_2N\text{-}C_6H_4\text{-}$	H-	25	100% hydrocarbon
$3,4\text{-}(CH_3O)_2C_6H_3\text{-}$	H-	-	100% alcohol
$3,4\text{-}(CH_3O)_2C_6H_3\text{-}$	H-	25	14.5% alcohol, 55.5% hydrocarbon†† 2[illegible]% high M.W. prod.
$3,4\text{-}(CH_3O)_2C_6H_3\text{-}$	H-	2.5	49% alcohol, 4[illegible]% hydrocarbon, 10% high M.W. prod.

† Composition was determined from the integrated n.m.r. spectra of the crude product which was obtained after removal of the solvent.

†† In addition to n.m.r. analysis of the crude mixture, homoveratrol b.p.110-114°/20mm n_D^{17} 1.5285 was also isolated

same ketone is reduced to the hydrocarbon by the catalysis of 10% boron fluoride.

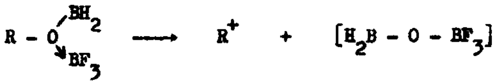
We also found that p-dimethylamino benzaldehyde is reduced to p-dimethylaminotoluene with diborane, this in contrast to the result of Biswas Houghton and Jackson who report that this compound was reduced internally to the hydrocarbon, but by the external generation method it gave the corresponding alcohol. The result of the external reduction could be reversed by the addition of $NaBH_4$ to the reaction mixture whereupon hydrogenolysis occured. It seems to us that the discrepancy between our results and those of Biswas Houghton and Jackson can be best explained by assuming that in their external reductions they had a large excess of boron fluoride which, by complex-formation with the dimethylamino group, neutralized its electron donating properties. The seemingly catalytic effect of added $NaBH_4$ was presumably due to its reaction with the BF_3 releasing thereby the dimethyl amino group from its Lewis salt. On the other hand, in the internal reductions of this aldehyde hydrogenolysis could probably be completed before the concentration of boron trifluoride (which was added dropwise) reached a sufficiently high value, to inhibit the reduction by salt formation.

The ketone ⟶ hydrocarbon conversion by diborane can be visualized as a multi stage process. The initial step, formation of an alkoxyborane is followed by slow heterolysis of the C–O bond to give a carbonium ion, and then by a fast hydride transfer to yield product.

$$R - OBH_2 \longleftrightarrow R - \overset{+}{O} = \overset{-}{B}H_2 \longrightarrow R^{+}[OBH_2]^{-} \longrightarrow RH + \{ OBH \}_n$$

The driving force for the heterolysis seems to be a result of the combination of two factors: 1) the ability of oxygen to donate electrons to the empty orbital of boron and 2) the stability of the emerging carbonium ion. Since the borate is a poor leaving group, the heterolysis could be promoted by the presence of electron releasing groups in the R of the alkoxyborane, and by electrophilic catalysts such as BF_3.

In our work only in the p-dimethylamino-benzyloxyborane and in the p-anisyl cyclopropyl carbinyloxyborane hydrogenolysis did occur spontaneously. All other cases reported here required the catalytic action of boron trifluoride. The latter conceivably facilitates the C–O bond fision either *via* its coordination to the oxygen,



$$R-\overset{BH_2}{\underset{BF_3}{O}} \longrightarrow R^+ + [H_2B-O-BF_3]$$

or through the formation of mixed alkoxyfluoroboranes, such as ROBHF or $ROBF_2$, thus conferring better leaving-group properties to the inorganic moiety relative to the CBH_2^- group.

Since the hydrogenolysis in the cyclopropane series occurs essentially without rearrangement, it appears that the trapping of the carbonium ion by hydride is the fast step of the reaction.

The foregoing results also indicate that the electron releasing ability of the cyclopropyl group is comparable to that of the anisyl group. It is not understood however why *p*-anisyl cyclopropyl ketone is more reactive towards hydrogenolysis than both dianisyl ketone and dicyclopropyl ketone.

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