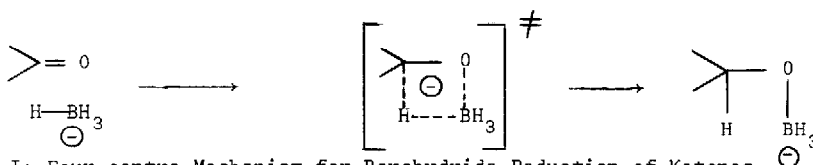


PHOTOCHEMICAL BOROHYDRIDE REDUCTIONS

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The evidence in the previous communication that reductions of ketones by sodium borohydride in 2-propanol do not occur by a four-centre mechanism, as shown below, is particularly satisfying from the point of view of orbital symmetry¹, since the simplest four-centre mechan-



Scheme I: Four-centre Mechanism for Borohydride Reduction of Ketones.

ism is a forbidden $[\pi 2s + \sigma 2s]$ cycloaddition, whereas neither the six-centre² nor the linear² mechanism would appear to be forbidden from this point of view. The fact that the hydroxylic solvent in these reductions plays an important role is evident not only from current work², but also from the fact that these reductions do not proceed at any appreciable rate in inert solvents, e.g. diglyme³. In diglyme, while the six-centre mechanism and any other mechanism involving hydroxylic solvent would clearly not be possible, the orbital symmetry restriction is the only obvious factor preventing the four-centre mechanism from occurring, and it is an intriguing point that under photochemical conditions this restriction is removed. In this connection, we wish to report that, in diglyme, the reduction of ketones by sodium borohydride is dramatically accelerated by irradiation. Whether or not this new photochemical reaction is indeed the allowed four-centre process is open to question.

Photochemical catalysis was tested by irradiating at 254 nm a solution of the ketone sodium borohydride in diglyme. As indicated in the table, reduction was complete within 20-90 minutes, under conditions where no reaction was detectable in the absence of irradiation.

TABLE
Photochemical Borohydride Reduction of
Cyclohexanones in Diglyme

Ketone	Time ^a (Min)	% Reduction ^c	Stereochemical Product Ratio (Cis:Trans)			
			NaBH ₄ hv diglyme	NaBH ₄ ⁷ Pr ⁱ OH	Solvent ⁶ hv	Sn(Bu ⁿ) ₃ H ⁵
2-methyl- cyclohexanone	90	94 ^b	26:74	30:70	--	24:76
4-methyl- cyclohexanone	20	>99	14:86	16:84	21:78	17:83
4- <u>t</u> -butyl- cyclohexanone	20	>99	12:88	14:86	18:82	13:87
3-methyl- cyclohexanone	20	>99	78:22	75:25	74:26	86:14
3,3,5-trimethyl- cyclohexanone	30	>99	44:56	45:55	68:32	54:46

^aNo attempt was made to reduce this to a minimum.

^bThe other 6% was not starting ketone, but comprised a number of other unidentified products.

^cBy GLC analysis on a 50 ft. S.C.O.T. TCEP column attached to a Perkin-Elmer 990 gas chromatograph.

Three main mechanisms for these photoreductions appear to warrant consideration: these are (a) the allowed four-centre process mentioned above; (b) free radical reduction similar to that proposed for the reduction of ketones by tri-n-butyl tin hydride⁵; and (c) photoreduction by solvent⁶. The latter possibility may be excluded by the observation that attempted photoreduction in the absence of sodium borohydride, but under otherwise identical conditions resulted in less than 1% reduction. Although there are at present insufficient data to distinguish rigorously the concerted and free-radical mechanisms, it has been noted that the free-radical reactions have differing stereoselectivities from concerted reductions⁵. Comparisons of stereoselectivities are therefore shown in the table, from which it is clear

that the stereoselectivities of various reductions are not widely different, but in cases where there is a difference, the result of photochemical borohydride reduction is closer to that of the concerted reaction than that of the radical reaction. Thus this new reaction may well proceed through the previously unobserved four-centre transition state, although this mechanistic point cannot be regarded as established. There are few previous reports of photochemical borohydride reductions, and although this would appear to be the first one involving reduction of a carbonyl group, there have recently been a number of reports of photochemical borohydride reductions of aromatic systems⁸⁻¹⁰.

This latest reduction is clearly of more mechanistic than synthetic interest, yet there is an obvious possible synthetic application worth exploring. Esters are not normally reduced by sodium borohydride¹¹, yet they might be under these new photochemical conditions: mechanistic conditions suggest a protected hemiacetal as a likely product leading, upon hydrolysis, to the corresponding aldehyde, if this reduction were to occur. Investigation of the photochemical borohydride reduction of esters showed that although a useful yield of aldehyde was not attainable, reduction does indeed occur, the major product being the corresponding primary alcohol. Based on reductions of methyl benzoate and methyl cyclohexanecarboxylate, conversions of 90% were achieved in 80 hours of irradiation either in alcoholic solvents or in diglyme¹².

Acknowledgement

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References and Footnotes

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