Alkaline-Earth Borohydrides and their Applications in Organic Syntheses

We have pointed out that the alkaline-earth metal borohydrides discovered by us are very suitable for the reduction of ketones and aldehydes to the corresponding alcohols[1]. The present communication deals with the application of these borohydrides—particularly of $Ca(BH_4)_2$—for reduction of other functional groups.

The most important of these applications is the reduction of carboxylic acid esters to primary alcohols. We have been able to reduce a great number of aliphatic and aromatic carboxylic esters, generally in excellent yields, by means of calcium borohydride. For example, we have reduced the following esters to the corresponding carbinols (yields in parentheses): ethyl *p*-nitrobenzoate (96 per cent), ethyl phenylacetate (90 per cent), ethyl glycinate (70 per cent), ethyl alaninate (73 per cent), threo ethyl *p*-nitrophenylserinate (88 per cent); for this last reduction, lithium–aluminium hydride is quite unsuitable[2].

The azlactones, too, proved to be well suited for reduction by the aid of calcium borohydride[3]; 2-phenyl-4-benzyliden-oxazol-5-one gave α-benzoyl-aminocinnamyl alcohol.

The above-mentioned reductions can be carried out with solutions of calcium borohydride in hydroxyl-free solvents (tetrahydrofurane); but the alcoholic solutions prepared by the metathesis of sodium borohydride and calcium chloride are equally suitable. In alcoholic medium, of course, to avoid the alcoholytic decomposition of the calcium borohydride, the temperature must be kept between about −20° and −10° C. (Esters with smaller reactivity are not reducible in alcoholic solution.)

It is very interesting that the reductions can also be successfully carried out in solvents of high water content (for example, in 50 per cent alcohol) provided that the temperatures employed are sufficiently low; thus threo ethyl-β-phenylserinate and ethyl *p*-nitrobenzoate are reducible in 50 per cent ethanol with good yields. The reductions are generally completed in 4–10 hr.

If required, it is possible to work in a hydroxyl-free solvent by the following technique: the solution of the ester in tetrahydrofurane is stirred for some hours with a mixture of calcium iodide and sodium borohydride at a temperature between 0° and 25° C., or, if necessary, at higher temperature. Obviously the reducing agent is 'nascent' calcium borohydride.

We have developed further methods for preparing the alkaline-earth metal borohydrides in solid form. For example, calcium borohydride can be obtained from the reaction of anhydrous calcium chloride and sodium borohydride in tetrahydrofurane. The reaction requires 4–8 hr. and thorough stirring (with a magnetic stirrer or a ball mill). The solution contains, after the sodium chloride has been centrifuged off, calcium borohydride of fairly good purity. (With such solutions esters with smaller reactivity, such as ethyl benzoate, are also reducible). The solution gives on evaporation *in vacuo* a crystalline tetrahydrofurane addition compound of calcium borohydride.

The reducing properties of strontium or barium borohydrides are very similar to those of calcium borohydride.

Our experimental results indicate that the calcium borohydride and other alkaline-earth metal borohydrides are reducing agents of higher reducing activity than the other borohydrides hitherto used for reduction purposes, namely, the borohydrides of sodium, potassium and lithium. This may be ascribed perhaps to the more covalent character of these compounds.

The general opinion, that esters are not reducible with sodium or potassium borohydride[4], must be corrected. In our experiments, we succeeded in reducing some esters with sodium and lithium borohydrides in alcoholic solution to primary alcohols in excellent yields. Nevertheless, some esters, which are readily reduced by alkaline-earth borohydrides, are not reducible by means of lithium or sodium borohydrides under similar conditions.

The alkaline-earth metal borohydrides are, in our opinion, among the most important reducing agents. They are suitable for the reduction of esters to primary carbinols, a reaction which is regarded as the most important function of lithium–aluminium hydride. In addition, the alkaline-earth borohydrides have a combination of features which is unique: solvents with hydroxyl groups (for example, ethanol, water) may be used; the selectivity of the reductions is greater than in the case of lithium–aluminium hydride; there is no danger of explosion and ignition, as contrasted with the latter; compounds sensitive to alkalis can also be reduced, as the solutions of alkaline-earth borohydrides are nearly neutral.

We believe that these compounds have good promise, *inter alia*, in the study of several groups of natural products, such as the proteins, polypeptides (determination of C-terminal residues[5]), sugar derivatives and polysaccharides.

A detailed account of this work will be published elsewhere.

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Inhibition of the First Limit of the Hydrogen – Oxygen Reaction by Ethane

A study of the inhibiting action of ethane on the second limit of the hydrogen–oxygen reaction in vessels coated with potassium chloride[1] shows that the main features of the inhibition are essentially similar to those reported for propane[2]. The reduction in explosion pressure with increasing mole fraction of ethane is almost exactly linear, and the quantity of inhibitor ($i_{1/2}$) required to halve the explosion pressure is approximately proportional to the mole fraction of oxygen, and approximately independent of the mole fraction of hydrogen, vessel diameter, and vessel surface. As in the case of propane, these main facts can be explained by introducing a termination reaction between hydrogen atoms and the hydrocarbon