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HYDROSTANNOLYSIS REACTIONS. PART I.

REDUCTION OF ESTERS.

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The facile reduction of alkyl halides by organotin hydrides has been shown to be a radical-chain reaction[1] for which the following chain-propagating steps ⁅(1) & (2), X = Halogen⁆ have been proposed:

$$R'_3Sn\cdot + RX \longrightarrow R'_3SnX + R\cdot \tag{1}$$

$$R\cdot + R'_3SnH \longrightarrow R'_3Sn\cdot + RH \tag{2}$$

We have now found that carboxylic acid esters, under more vigorous conditions, can similarly be reduced to the corresponding hydrocarbons by trialkyltin hydrides (3):

$$ROCOR'' + R'_3SnH \longrightarrow RH + R'_3SnOCOR'' \tag{3}$$

and evidences so far obtained point to the same radical mechanism ⁅(1) & (2), X = OCOR"⁆. Examples in Table I provide an indication of the scope of the reaction.

TABLE I. Reduction of Benzoates $PhCO_2R$ with Tri-n-butyltin Hydride

R .mole)[a]	Radical Source[b]	Temp. °C	Reaction Time[c] hr.	Unreacted Benzoate Recovered[d] m.mole	Yield of $n\text{-}Bu_3SnOCOPh$[d] (Hydrocarbon)[e] m.mole	% Reduction[f]
t-Bu (8.4)	UV	80	40	4.7	4.0	48
$PhCH_2$ (10.7)	UV	"	10	3.2	7.5	70
Ph_2CH (9.1)[g]	AIBN	"	24	2.4	7.1 (5.6)	78
$CH_2{=}CHCH_2$ (7.3)	UV	"	7	1.8	2.2 (3.0)[h]	30
n-Bu (11.9)	UV	130	50	9.4	1.2	10
sec-Bu (7.6)	UV	"	44	5.2	2.2	29
t-Bu (7.1)	UV	"	30	3.1	4.3	61
Cyclohexyl (5.4)	$n\text{-}Bu_2O_2$	"	27	3.8	1.1	20
Ph (7.2)	UV	"	6.5	4.4	2.3	33
$PhCH_2$ (12.1)	UV	"	3.5	2.9	9.3 (9.1)	77
$PhCH(CH_3)$ (12.5)	$n\text{-}Bu_2O_2$	"	7.5	1.7	10.7	86
Ph_2CH (8.2)	$n\text{-}Bu_2O_2$	"	6	1.3	7.3 (6.4)	89
Ph_2CH (6.4)	UV	"	3	1.7	5.1	80
Ph_3C (2.2)[g]	UV	"	2	0.6	1.7 (1.5)[i]	77
Ph_3C (2.9)	$n\text{-}Bu_2O_2$	"	5	1.0	2.1 (1.7)[i]	74
$CH_2{=}CHCH_2$ (8.7)	UV	"	4	2.4	3.4 (3.1)[h]	39
2-Cyclohexenyl (6.6)	UV	"	4.5	1.7	5.0	74
$PhCH{=}CHCH_2$ (5.1)	UV	"	2.5	1.4	3.8 (3.3)[j]	75

(a) Unless otherwise stated, equivalent amount of tri-n-butyltin hydride was used without solvent.

(b) For UV, a G.E. 275-watt sunlamp was used; AIBN= azobisisobutyronitrile added was 20 mole %, and di-t-butyl peroxide used was 3-5 mole %.

(c) Reaction was followed to the disappearance of the Sn-H band at ~ 1815 cm^{-1} in the infrared region.

(d) By quantitative infrared spectrophotometric analysis with estimated accuracy of ±5% .

(e) By glc analysis with an internal standard, unless otherwise stated.

(f) Based on $n\text{-}Bu_3SnOCOPh$ obtained.

(g) t-Butylbenzene was used as solvent.

(h) Propylene was detected as its dibromide. Yield reported was that of the addition product, (3-benzoyloxypropyl)tributyltin.

(i) Isolated by column chromatography.

(j) Mixture consists of allylbenzene and trans-propenylbenzene in the ratio of 1.6:1 and trace amount of cis-propenylbenzene.

The radical-chain nature of the hydrostannolysis of esters was demonstrated by the profound catalytic effects which various free radical initiators exerted on the reaction:

TABLE II. Catalysis of Ester Reduction by Various Radical Initiators

$PhCO_2R$	R'_3SnH Used	Temp.	Time	% Reduction	
R	R'	°C	hr.	Uncatalyzed	Catalyzed(Initiator)[a]
2-Cyclohexenyl	n-Pr	80	20	none	49 (AIBN)
$PhCH_2$	n-Bu	"	10	none	70 (UV)
2-Cyclohexenyl	"	130	4.5	8	74 (UV)
$PhCH_2$	"	"	7	9	75 ($n-Bu_2O_2$)

(a) See Table I, footnote (b).

Further evidence in support of the radical mechanism was obtained from the reduction of optically active α-phenethyl benzoate[2] with tri-n-butyltin deuteride in benzene solution at 80°C with AIBN as initiator. The isolated α-deuteriophenylethane (96% α-monodeuterated) was found to be racemic while recovered unreacted ester was found to retain its original optical activity, indicating that no racemization of the starting material occurred prior to reduction.

Internal competitive experiment showed that the reduction of benzyl benzoate by tri-n-butyltin hydride is ca. 40 times slower than that of benzyl chloride at 80°C, and is consistent with the observations that whereas hydrostannolysis of allyl halide[1(a)] gave no addition product, that of allyl benzoate gave ca. 40% (Table I) adduct indicating that in the latter, addition to terminal double bond and reduction are equally facile. In contrast, addition to internal double bond such as in the case of 2-cyclohexenyl benzoate or cinnamyl benzoate is slow compared with hydrostannolysis. The reaction appears otherwise to be free from complication as shown by the quantitative recovery in each case of unreacted ester (Table I). The only contaminants observed are the decomposition products of trialkyltin hydride, viz., tetraalkyltin, hexaalkylditin and metallic tin.

Although for convenience benzoates were chiefly used in this investigation, other carboxylic acid esters were found to be similarly reduced, albeit at different rates. Results of competitive experiments with four different carboxylic acid esters are gathered in Table III.

TABLE III. Relative Rates of Reduction of Esters RCO_2CH_2Ph by Tri-n-butyltin Hydride

R	Relative Rate[a] At 130°C[b]	Relative Rate[a] At 80°C[c]
CH_3	1.0	1.0
H	4.8 ± 0.3	7.5 ± 0.5
Ph	7.1 ± 0.3	6.3 ± 0.3
CF_3	30.0 ± 0.3	35.0 ± 0.4

(a) Each reduction was done in duplicate or triplicate, and was initiated with a G.E. 275-watt sunlamp. Unreacted esters were analyzed by glc.
(b) Without solvent.
(c) With benzene as solvent.

It can be seen that electron-withdrawing substituent facilitates the reduction, whereas electron-donating group has the opposite effect. Although the rate difference is not great it nevertheless parallels the relative acid strength of the carboxylic acids, and is suggestive of the displacement step (1) occurring via attack of the trialkyltin radical on the ethereal-oxygen atom of the ester. Definitive conclusion on this point is being sought by the use of O^{18}-labelled ester.

The hydrostannolysis of carboxylic esters provides a new method of generating radicals and as in the case of the hydrostannolysis of halides[1(c)] is of value in the preparation of specifically deuterated (or tritiated) compounds.

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References

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