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Hydrosilation of α,β-Unsaturated Esters[1)]

Addition of silicon hydrides on α,β-unsaturated esters in principle could occur in three directions to give α- and β-silylated product (1,2-addition) and keten silyl alkyl acetal (1,4-addition).

$$-\overset{|}{C}=\overset{|}{C}-COOR' \xrightarrow{R_3SiH} -\overset{|}{C}H-\overset{|}{C}(SiR_3)-COOR';\quad -\overset{|}{C}(SiR_3)-\overset{|}{C}H-COOR';\quad -\overset{|}{C}H-\overset{|}{C}=C(OR')OSiR_3$$

This hydrosilation reaction induced by chloroplatinic acid or platinum metal catalyst has been most extensively studied on acrylate and metacrylate, and the results[2)] show that the course of addition depends on the structure of ester and the nature of silicon hydride. Metacrylate gives exclusively β-adduct irrespective of the composition of silicon hydride.[2c,d)] On the other hand, in the case of acrylate chlorosilanes show the tendency to give the mixtures of three adducts,[2a)] while triethylsilane leads regiospecific addition though ambiguity exists concerning the structure of the product.[3)] If one could control the orientation toward 1,4-addition, the hydrosilation of α,β-unsaturated esters will become a valuable method not only for the preparation of synthetically useful keten silyl acetals,[4)] but also for the selective hydrogenation of the olefinic bond since keten silyl acetals are readily hydrolyzed to saturated esters.[4a)] This communication describes the results of our investigation along this line in which several methyl 2-alkenoates were hydrosilated with trialkylsilanes (particularly trimethyl- and triethylsilanes) in the presence of chloroplatinic acid or tris (triphenylphosphine) chlororhodium.

Chloroplatinic Acid Catalyzed Hydrosilation

To a mixture of an unsaturated ester (20—25 mmoles) listed in Table I and slight excess of silane in a pressure tube was added 0.5 mole % H_2PtCl_6 (as 0.2 M iso-PrOH solution) and the mixture was heated-at 60°. After the completion of the reaction (3 to 5 hr) which was monitored by gas chromatography (GC), the reaction mixture was distilled, and the distillate was subjected to GC analysis after methanolysis at room temperature by which keten silyl acetals were transformed into saturated methyl esters.[5)] The results summarized in Table I show that no selective addition occurred except metacrylate which gave only β-adduct showing strong steric effect of α-substituent in this hydrosilation. In the case of acrylate trimethylsilane led all addition modes, but more bulky triethylsilane gave no α-adduct, providing a mixture of β- and 1,4-adducts even under the same reaction condition as reported to give either product solely.[3)] Crotonate and its homologs, on the other hand, did undergo 1,4-addition in excess. The interesting fact discovered in the experiment with crotonate was the formation of 2-ethyl-3-methylglutarate. That the precursor of the glutarate isolated

1) Support for this work by a grant from Hoan-sha (Osaka) is acknowledged.

2) *a*) A.D. Petrov, S.I. Sadykh-Zade, and E.I. Filatova, *J. Gen. Chem. USSR*, **29**, 2896 (1959) [*Chem. Abstr.*, **54**, 11984 (1960)]; *b*) F. Rijkens, M.J. Janssen, W. Drenth, and G.J.M. van der Kerk, *J. Organometal. Chem.*, 2, 347 (1964); *c*) L.H. Sommer, F.P. Macbay, O.W. Steward, and P.G. Campbell, *J. Am. Chem. Soc.*, **79**, 2764 (1957); *d*) J.W. Curry and G.W. Harrison, *J. Org. Chem.*, **23**, 627 (1958).

3) A.D. Petrov, *et al.*[2a)] claimed to have obtained a keten acetal (1,4-addition product) without spectroscopic evidence. Later, F. Rijkens, *et al.*[2b)] isolated only β-triethylsilylpropionate (1,2-addition product).

4) *a*) Y-N. Kuo, T. Chen, C. Ainsworth, and J.J. Bloomfield, *Chem. Commun.*, **1971**, 136; *b*) P.L. Creger, *Tetrahedron Letters*, **1972**, 79.

5) Saturated esters were identified by comparison of GC retention times with those of authentic samples. Other products were purified by preparative GC, and identified by infrared (IR), nuclear magnetic resonance (NMR) and mass (MS) spectroscopy. Yields were determined by GC using internal standards.

TABLE I. Chloroplatinic Acid Catalyzed Hydrosilation of α,β-Unsaturated Esters[a)]

Unsaturated ester	Silane	% yields of products after methanolysis[5)]			
		Saturated ester	α-R_3Si-[b)]	β-R_3Si-[c)]	Dimer
CH_2=CH–COOMe	Me_3SiH	22	33	4	—
	Et_3SiH*	42	—	26	—
CH_2=C(Me)COOMe	Me_3SiH	—	—	69	—
CH_3–CH=CH–COOMe	Me_3SiH	28	17	—	54 (II, R=Me)
	Me_3SiH*	50	13	—	—
C_2H_5–CH=CH–COOMe	Me_3SiH	56	3	—	25 (II, R=Et)
iso-C_3H_7–CH=CH–COOMe	Me_3SiH	60	3	—	—

a) In the presence of 0.5 mole% H_2PtCl_6 except asterisked runs where 10^{-3} mole% catalyst was used.
b) IR $\nu_{C=O}$: 1720—1725 cm^{-1}
c) IR $\nu_{C=O}$: around 1745 cm^{-1}

$$2\,R\text{–}CH\text{=}CH\text{–}COOMe \xrightarrow[H_2PtCl_6]{Me_3SiH} R\text{–}CH_2\text{–}C(OMe)\text{=}CH(R)\text{–}CH_2COOMe\ (OSiMe_3) \xrightarrow{MeOH} R\text{–}CH_2\text{–}CH(R)\text{–}CH_2COOMe\ (COOMe)$$

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by preparative GC is the mono keten acetal of the structure I (R=Me, mixture of geometrical isomers) was indicated by spectral data. Such reductive dimerization induced by hydrosilation was also observed with methyl 2-pentenoate though in less yield, but not with 4-methyl-2-pentenoate showing that the bulkiness of alkyl group might exert inhibiting effect.[6)]

Although the dimerization could have been prevented by reducting the amount of catalyst and an acceptable yield of 1,4-adduct was obtained (Table I, for crotonate), undesired α-silylated product was still accompanied with. We, therefore, turned our attention to employ tris(triphenylphosphine)chlororhodium for the catalyst, since Ojima, *et al.*[7)] recently showed that it is such a useful catalyst as chloroplatinic acid[8),9)] for the hydrosilation of α,β-unsaturated ketones and aldehydes yielding silyl enolethers (*via* 1,4-addition) though in some cases choice of hydrosilane is critical compared with chloroplatinic acid catalysis.

Tris(triphenylphosphine)chlororhodium Catalyzed Hydrosilation

A mixture of methyl crotonate (10 mmoles), slight excess of trimethylsilane, and 3×10^{-3} mole % of $[(C_6H_5)_3P]_3RhCl$ was heated to 60°, when almost instantaneously completed the reaction providing 77% yield of the corresponding keten trimethylsilyl acetal and small amount of α-adduct. Moreover, exclusive 1,4-addition was observed with Et_3SiH and n-Pr_3SiH, and the keten acetals were easily isolated by distillation of the reaction mixture. The effectiveness of $[(C_6H_5)_3P]_3RhCl$-Et_3SiH combination for our present purpose was further demonstrated with other esters as shown in Table II. Even metacrylate did undergo 1,4-addition. Only exceptional case was found with acrylate.

In conclusion, from the standpoint of the initial purpose of the present investigation, chloroplatinic acid is not fully satisfactory catalyst for the hydrosilation of α,β-unsaturated esters, though the same catalyst has been successfully used for the regiospecific 1,4-addition to conjugated enones[8)] and dienones[9)] yielding silyl enolethers. Tris(triphenylphosphine)-

6) The mechanism of this newly discovered dimerization reaction will be discussed in a full paper.
7) I. Ojima, T. Kogure, and Y. Nagai, *Tetrahedron Letters*, **1972**, 5085.
8) A.D. Petrov and S.I. Sadykh-Zade, *Doklady Akad, Nauk SSSR*, **121**, 119 (1958) [*Chem. Abstr.*, **53**, 1207 (1959)].
9) E. Yoshii, H. Ikeshima, and K. Ozaki, *Chem. Pharm. Bull.* (Tokyo), **20**, 1827 (1972).

TABLE II. $[(C_6H_5)_3P]_3RhCl$ Catalyzed Hydrosilation of α,β-Unsaturated Esters[5]

Unsaturated ester	Silane	Temp. °C (min)	% yield of keten trialkylsilyl methyl acetal[a]	% yield of 1,2-addition product
CH_3–CH=CH–COOMe	Me_3SiH	60(10)	77.0	8.6 (α-silyl)
	Et_2SiH	100(1)	85.6	—
	n-Pr_3SiH	100(1)	73.5[b,c]	—
C_2H_5–CH=CH–COOMe	Et_3SiH	100(1)	75.4	—
iso-C_3H_7–CH=CH–COOMe	Et_3SiH	100(1)	76.5	—
CH_2=C(Me)COOMe	Et_3SiH	100(1)	70.0[b,d]	—
CH_2=CH–COOMe	Et_3SiH	100(1)	31.6	38.9 (β-silyl)

a) The yields are based on saturated esters after methanolysis except noted. Geometrical isomerism of keten acetals was not determined.
b) isolated yield obtained by short-path distillation
c) bp 74° (1 mmHg); IR $\nu_{C=C}$: 1678 cm^{-1}
d) bp 38—40° (1 mmHg); IR $\nu_{C=C}$: 1705 cm^{-1}

chlororhodium, on the other hand, was found to be the catalyst of chloice for the preparation of keten silyl acetals from α,β-unsaturated esters, particularly under combination with triethylsilane.

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Enhancement of the Fluorescence Intensity of Dansyl Protamine in the Presence of Sulfated Carbohydrates and Its Application to Assay of Mucopolysaccharides and Synthetic Sulfates of Mono-, Oligo-, and Polysaccharides

Determination of naturally occuring mucopolysaccharides (MPS) and synthetic sulfates of carbohydrates are currently of much biological and clinical importance.[1] Microamount of these saccharides has hitherto been assayed by the use of metachromasy of dyes[2] and enzymatic degradation.[3] However, metachromasy is largely affected by pH, temperature, and ionic strength of the reaction mixture. Moreover, the reagent blank shows large absorbance in this method. On the other hand, enzymatic method is only applicable to limited number of MPS and not applicable to synthetic sulfates. In the present study, protamine, which has been demonstrated to bind tightly with heparin and other mucopolysaccharides,[4] was labeled with

1) *a*) J.S. Brimacombe and J.M. Webber, "Mucopolysaccharides," Elsevier Publishing Co. Amsterdam, 1964; *b*) K. Anno, E. Hasegawa, and Z. Yoshizawa, eds. "Muko-tato Jikken-ho," (in Japanese) Vol. 1, 2, Nankodo, Tokyo, 1973.
2) L.B. Jaques and H.J. Bell, "Methods of Biochemical Analysis," Vol. 7, ed. by D. Glick, Interscience Publishers, New York, 1959, p. 253; N. Seno, K. Anno, K. Kondo, S. Nagase, and S. Saito, *Anal. Biochem.* 37, 197 (1970).
3) H. Saito, T. Yamagata, and S. Suzuki, *J. Biol. Chem.*, 243, 1536 (1968).
4) Ref. 1*a*) pp. 117—118.