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STUDIES ON KETENE AND ITS DERIVATIVES. CXV.1)
REACTION OF DIKETENE WITH ORGANOMETALLICS IN THE PRESENCE OF THE NICKEL- OR PALLADIUM-PHOSPHINE COMPLEX

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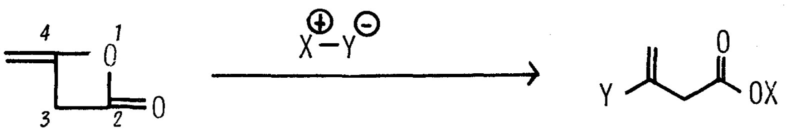
Reaction of diketene (1) with alkyl, alkenyl, alkynyl, and aryl organometallics proceeded under catalysis of nickel(Ni)- or palladium(Pd)-phosphine complex to give 3-substituted 3-butenoic acids (2a-k).

KEYWORDS —— diketene; Grignard reagent; alkenylaluminium; alkynylzinc chloride; arylzinc chloride; Pd-catalyst; Ni-catalyst; 3-butenoic acid

The most typical reaction of diketene (1) is acylation of a nucleophile to cause ring fission between the carbonyl carbon (C-2) and the oxetane ring oxygen (O-1) giving an acetoacetic acid derivative.2) On the other hand, few papers have reported novel ring fission pattern between the methylene carbon (C-4) and the ring oxygen (O-1).3)



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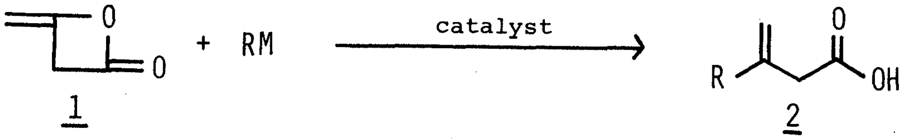
Itoh *et al.*3b) reported the reaction of 1 with trimethylsilylmethylmagnesium chloride in the presence of nickel (II) chloride yielded 3-trimethylsilylmethyl-3-butenoic acid. Recently, Fujisawa *et al.*3c) have shown that cobalt (II) iodide is effective for the reaction of 1 with alkyl Grignard reagents affording 3-alkyl 3-butenoic acids. However, they have described that the reaction of 1 with phenyl or vinyl Grignard reagent gives no satisfactory result even in the presence of these catalysts. In this communication, we report that 1 reacts with alkyl, alkenyl, alkynyl, and aryl organometallics in the presence of Ni- or Pd-phosphine complex to give 3-substituted 3-butenoic acids.

The efficient nickel-catalyzed cross-coupling reaction of vinyl halide with Grignard reagents was reported by Kumada *et al.*4) We investigated the reaction of 1 with alkyl Grignard reagents in the presence of NiCl$_2$(dppp)5) [dppp = PPh$_2$-(CH$_2$)$_3$PPh$_2$] to obtain 3-alkyl-3-butenoic acids (2a-c) (run 2 - 4). A typical procedure is as follows: Ether (50 ml) and NiCl$_2$(dppp) (1.06 g, 0.002 mol) were added to a solution of BuMgBr prepared from Mg (0.80 g, 0.033 g atom) and BuBr (4.11 g, 0.03 mol) in ether (30 ml). A solution of 1 (1.68 g, 0.02 mol) in ether

Table I. Reaction of Diketene (1) with Organometallics



Run	R	M	Catalyst[a]	Temperature[b] (°C)	Solvent	Product	
						No.	Yield (%)
1	C_4H_9	MgBr	A	-70	ether	2a	26
2	C_4H_9	MgBr	B	-70	ether	2a	51
3	C_3H_7	MgBr	B	-70	ether	2b	43
4	C_2H_5	MgBr	B	-70	ether	2c	46
5	$C_5H_{11}CH=CH$	$Al(iso\text{-}C_4H_9)_2$	C	-10 — rt	hexane - THF	2d	35
6	$C_5H_{11}CH=CH$	$Al(iso\text{-}C_4H_9)_2$	D	-10 — rt	hexane - THF	2d	54
7	$C_4H_9CH=CH$	$Al(iso\text{-}C_4H_9)_2$	D	-10 — rt	hexane - THF	2e	51
8	$C_3H_7CH=CH$	$Al(iso\text{-}C_4H_9)_2$	D	-10 — rt	hexane - THF	2f	51
9	$C_5H_{11}C\equiv C$	ZnCl	C	rt	THF	2g	52
10	$C_5H_{11}C\equiv C$	ZnCl	D	rt	THF	2g	38
11	$C_3H_7C\equiv C$	ZnCl	C	rt	THF	2h	60
12	$C_6H_5C\equiv C$	ZnCl	C	rt	THF	2i	47
13	C_6H_5	ZnCl	C	rt	ether - THF	2j	13
14	C_6H_5	ZnCl	D	rt	ether - THF	2j	44
15	*m*-CH_3-C_6H_4	ZnCl	D	rt	ether - THF	2k	51

a) A = $NiCl_2(PPh_3)_2$, B = $NiCl_2(dppp)$, C = $Ni(PPh_3)_4$,
D = $PdCl_2(PPh_3)_2$ + iso-Bu_2AlH.

b) rt: room temperature.

(20 ml) was added to this mixture at -70°C. The reaction mixture was stirred below -70°C for 3 h and quenched with aq. HCl. The organic layer thus separated was extracted with 5% aq. $NaHCO_3$. The aqueous layer was acidified with aq. HCl and the resulting mixture was extracted with ether. The extract was dried over $MgSO_4$ and concentrated. Distillation of the residue afforded 1.46 g (51%) of 3-butyl-3-butenoic acid (2a). bp 100°C (2 mmHg).[6] ^{1}H-NMR ($CDCl_3$) δ: 0.68 - 2.50 (9H, m, C_4H_9), 3.06 (2H, s, CH_2CO), 4.93 (2H, s, $=CH_2$), 9.90 (1H, br, COOH). IR ($CHCl_3$): 1705 (C=O), 1640 (C=C), 900 ($C=CH_2$) cm^{-1}.

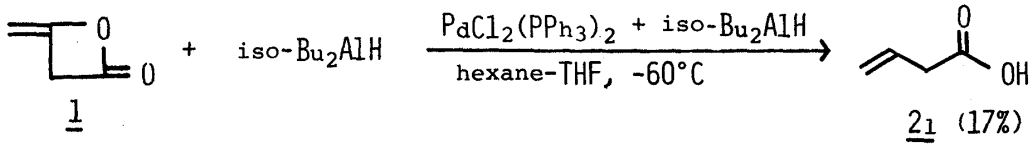
Negishi *et al.* reported that cross-coupling products were obtained by the reaction of alkenyl halides or aryl halides with 1-alkenyldiisobutylaluminiums,[7] alkynylzinc chlorides,[8] or arylzinc chlorides[9] in the presence of Pd(0)- or Ni(0)-phosphine complex. Therefore, we examined the reaction of 1 with these organometallics.

The reaction of 1 with alkenylaluminiums was more effectively catalyzed by a mixture of $PdCl_2(PPh_3)_2$[10] and iso-Bu_2AlH than $Ni(PPh_3)_4$[11] to give (*E*)-3-methylene-4-alkenoic acids (2d-f) stereospecifically (run 5 - 8). A typical procedure is as follows: A 25% hexane solution of iso-Bu_2AlH (0.8 ml, 0.0014 mol) and a solution of 1 (0.84 g, 0.01 mol) in THF (20 ml) were added sequentially to a suspension of $PdCl_2(PPh_3)_2$ (0.49 g, 0.0007 mol) in THF (15 ml). (*E*)-1-Heptenyldiisobutylaluminium,[12] prepared from 1-heptyne (1.44 g, 0.015 mol) and a 25% hexane solution of iso-Bu_2AlH (8.0 ml, 0.014 mol), was added to the mixture below -10°C. The reaction mixture was stirred at room temperature for 2.5 h. The residue obtained in a way similar to that described for 2a was subjected to silica gel column chromatography (hexane - ether) to furnish 0.98 g (54%) of (*E*)-3-methylene-4-decenoic acid (2g). bp 130°C (0.1 mmHg). ^1H-NMR ($CDCl_3$) δ: 0.7 - 2.6 (11H, m, C_5H_{11}), 3.24 (2H, s, CH_2CO), 5.03 and 5.12 (each 1H, s, $=CH_2$), 5.67 (1H, dt, J = 17 Hz, J = 6 Hz, $CH_2\underline{CH}=$), 6.16 (1H, d, J = 17 Hz, $=CH-C=$), 9.87 (1H, br, COOH). IR ($CHCl_3$): 1705 (C=O), 965 (HC=CH), 900 ($C=CH_2$) cm^{-1}.

The reaction of 1 with alkynylzinc chlorides was effectively catalyzed by $Ni(PPh_3)_4$ giving 3-methylene-4-alkynoic acids (2g-i) (run 9 - 12). A typical procedure is as follows: A 25% hexane solution of iso-Bu_2AlH (1.6 ml, 0.0028 mol) and a solution of 1 (0.84 g, 0.01 mol) in THF (10 ml) were added sequentially to a solution of $Ni(acac)_2$ (0.36 g, 0.0014 mol) and triphenylphosphine (1.47 g, 0.0056 mol) in THF (10 ml). To the mixture was added at room temperature 1-pentynylzinc chloride[8] prepared from 1-pentyne (1.02 g, 0.015 mol) in THF (15 ml), a 15% hexane solution of BuLi (8.5 ml, 0.014 mol), and zinc chloride (2.05 g, 0.015 mol). The reaction mixture was stirred at room temperature for 2 h. The residue obtained by the usual manner was purified by silica gel column chromatography (hexane - ether) to give 0.91 g (60%) of 3-methylene-4-octynoic acid (2h). bp 150 °C (0.05 mmHg). ^1H-NMR ($CDCl_3$) δ: 0.96 (3H, t, J = 8 Hz, CH_3), 1.54 (2H, dt, J = 8 Hz, J = 8 Hz, $\underline{CH_2}CH_3$), 2.27 (2H, t, J = 8 Hz, $CH_2C\equiv$), 3.18 (2H, s, CH_2CO), 5.31 and 5.44 (each 1H, s, $=CH_2$), 9.83 (1H, br, COOH). IR ($CHCl_3$): 2200 ($C\equiv C$), 1705 (C=O), 905 ($C=CH_2$) cm^{-1}.

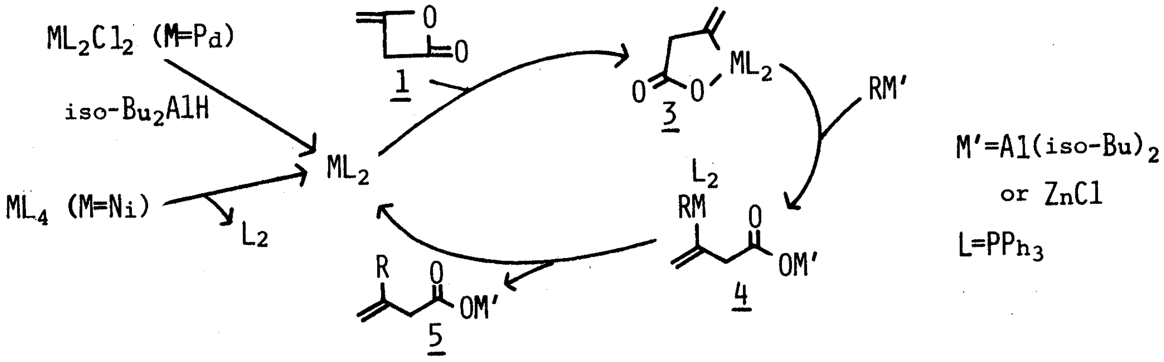
Similarly, the reaction of 1 with arylzinc chloride,[9] prepared from aryllithium and zinc chloride in ether, proceeded in the presence of Pd(0)-catalyst to give 3-aryl-3-butenoic acids (2j-k) in moderate yields (run 13 - 15).

However, the reaction of 1 with iso-Bu_2AlH in the presence of Pd(0)-catalyst afforded 3-butenoic acid (2l) in a low yield.



These results show that ring fission between the methylene carbon (C-4) and the ring oxygen (O-1) of 1 occurs not only with alkyl organometallics but also with alkenyl, alkynyl, and aryl ones. In view of the ready availability of the catalysts or organometallics, and the mildness of the reaction conditions, these reactions will be useful for the preparation of various 3-substituted 3-butenoic acids.

Although the detailed mechanism of the reaction in the presence of Ni(0) or Pd(0)-catalyst has not been studied, we considered the following pathway.



The initial step must involve the oxidative addition of 1 to a Pd- or Ni-complex to form a cyclic intermediate (3), which is analogous to that of the cross-coupling reaction[4,7,9,13] of alkenyl halide with organometallics. Complex 4, formed *via* transmetallation from the reaction of 3 with organometallics, is transformed into the product 5 by reductive elimination.

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