Chem. Pharm. Bull.
31(12)4346—4354(1983)

Studies on Ketene and Its Derivatives. CXVIII.[1] Nickel- or Palladium-Catalyzed Reaction of Diketene with Organometallics. Synthesis of 3-Substituted 3-Butenoic Acids[2]

YOSHIHITO ABE, MASAYUKI SATO,* HIROYUKI GOTO, RIE SUGAWARA,
ERI TAKAHASHI, and TETSUZO KATO

Pharmaceutical Institute, Tohoku University,
Aobayama, Sendai 980, Japan

(Received April 26, 1983)

The reaction of diketene (**1**) with some organometallics was investigated. The reaction of **1** with benzyl Grignard reagents in the presence of nickel(II) chloride afforded 3-benzyl-3-butenoic acids **2a**—**e**. In the presence of dichloro[1,3-bis(diphenylphosphino)propane]nickel, primary alkylmagnesium bromides reacted with **1** to give 3-methylenealkanoic acids **2g**—**i**. (*E*)-1-Alkenyldiisobutylaluminiums, in the presence of Pd(0)-catalyst, reacted with **1** to give 3-methylene-4-alkenoic acids **5a**—**c**. Similarly, alkynyl- and aryl-zinc chlorides gave 3-methylene-4-alkynoic acids **7a**—**d** and 3-aryl-3-butenoic acids **8a**—**c**, respectively.

Keywords——diketene; Grignard reagent; alkenylaluminium; alkynylzinc chloride; arylzinc chloride; palladium-catalyst; nickel-catalyst; 3-butenoic acid; 3-substituted 3-butenoic acid

Diketene[3] (**1**) is an enol lactone of acetoacetic acid, and its most typical reaction is acylation of nucleophiles[4] to cause ring fission between the carbonyl carbon (C-2) and the oxetane ring oxygen (O-1), giving acetoacetic acid derivatives. Other typical reactions involve addition[5] to a double bond with similar opening of the β-lactone. Some reactions involve only the olefinic double bond to give compounds with the β-lactone ring intact.[6]

On the other hand, Itoh *et al.*[7] reported the reaction of **1** with trimethylsilylmethylmagnesium chloride in the presence of nickel(II) chloride to yield 3-trimethylsilylmethyl-3-butenoic acid. This involves a novel ring fission pattern of **1** between the methylene carbon (C-4) and the ring oxygen (O-1).

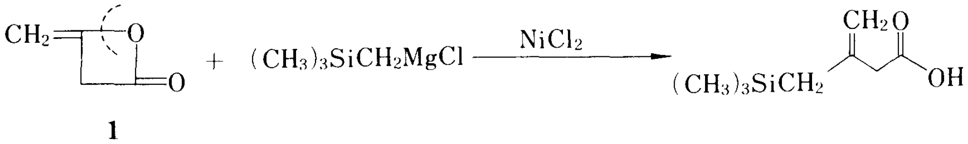
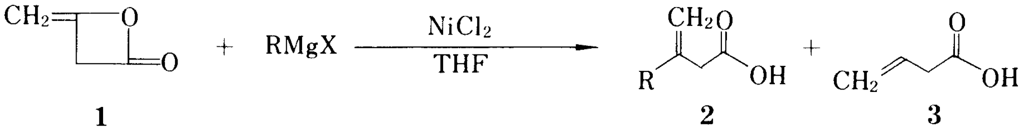


Chart 1

However, they stated that the reaction of **1** with butyl, phenyl, or vinyl Grignard reagents gave no satisfactory result. We now report that **1** reacts with alkyl, benzyl, alkenyl, alkynyl, and aryl organometallics, or a metal hydride in the presence of a nickel (Ni) or palladium (Pd) catalyst to give 3-substituted 3-butenoic acids.

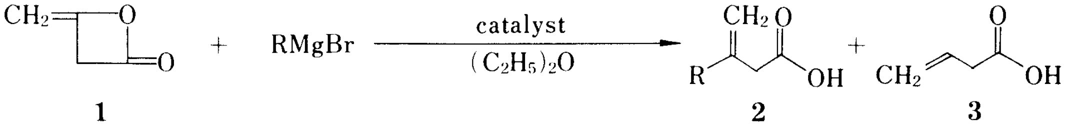
When **1** (0.02 mol) was treated with a mixture of benzylmagnesium chloride (0.03 mol) and nickel(II) chloride (0.003 mol), 3-benzyl-3-butenoic acid (**2a**) was obtained in 53% yield (run 1). Under similar conditions, some benzyl Grignard reagents afforded the desired acids **2b**—**e** in moderate yields (run 2—5). The reaction of **1** with neopentylmagnesium chloride also furnished the expected acid **2f** in 31% yield (run 6). Butyl- or ethyl-magnesium bromide reacted with **1** to give mixtures of the corresponding acids **2g**, **h** and 3-butenoic acid (**3**) in

Table I. Reaction of Diketene (**1**) with Grignard Reagents in the Presence of Nickel(II) Chloride



Run	R	X	No.	**2** Yield (%)	**3** Yield (%)
1	$C_6H_5CH_2$	Cl	**2a**	53	—
2	p-CH_3O–$C_6H_4CH_2$	Cl	**2b**	45	—
3	o-CH_3O–$C_6H_4CH_2$	Cl	**2c**	48	—
4	p-CH_3–$C_6H_4CH_2$	Cl	**2d**	70	—
5	m-CH_3–$C_6H_4CH_2$	Br	**2e**	34	—
6	$(CH_3)_3CCH_2$	Cl	**2f**	31	—
7	C_4H_9	Br	**2g**	Trace	Trace
8	C_2H_5	Br	**2h**	Trace	Trace

Table II. Reaction of **1** with Primary Alkyl Grignard Reagents in the Presence of Ni–Phosphine Complex



Run	R	Catalyst[a]	No.	**2** Yield (%)	**3** Yield (%)
9	C_4H_9	A	**2g**	26	6
10	C_4H_9	B	**2g**	51	—
11	C_3H_7	A	**2i**	25	9
12	C_3H_7	B	**2i**	43	—
13	C_2H_5	B	**2h**	46	—

a) A, $NiCl_2(PPh_3)_2$; B, $NiCl_2$(dppp).

poor yields (run 7 and 8). These results are summarized in Table I. However, aryl or alkenyl Grignard reagents did not give the desired acids under similar conditions. Thus, it was found that only Grignard reagents having no β-hydrogen, such as benzyl, neopentyl, and trimethylsilyl ones, afforded the desired acids in moderate yields. These results show that the reaction is influenced by the stability[8)] of an intermediate R_2Ni formed by the reaction of nickel(II) chloride and a Grignard reagent. β-Hydrogen elimination[9)] from R_2Ni is assumed to be a dominant reaction in the case of alkyl Grignard reagents containing β-hydrogen.

It is known that the cross-coupling reaction of alkenyl halides with alkyl Grignard reagents in the presence of some Ni-phosphine catalysts occurs without β-hydrogen elimination.[10)] Thus, we examined the reaction of **1** with Grignard reagents using these catalysts.

When **1** was added to a mixture of butylmagnesium bromide and bis(triphenylphosphine)nickel dichloride [$NiCl_2(PPh_3)_2$] in ether, the desired acids **2g** and **3** were obtained in 26 and 6% yields, respectively (run 9). A similar reaction in the presence of dichloro[1,3-bis(diphenylphosphino)propane]nickel [$NiCl_2$(dppp)] afforded exclusively **2g** in 51% yield (run 10). Propyl or ethyl Grignard reagents also gave similar results (run 11—13) as shown in Table II. However, isopropyl, styryl, and phenyl Grignard reagents did not give the desired acids with Ni-phosphine catalysts. Recently, Fujisawa *et al.*[11] reported independently that cobalt(II) iodide also catalyzed the reaction of **1** with primary alkyl Grignard reagents to give 3-methylenealkanoic acids. These results show that NiCl$_2$(dppp) and cobalt(II) iodide catalysts are applicable only to the reaction of **1** with primary alkyl Grignard reagents.

Although the precise mechanism of this nickel-catalyzed reaction is not clear at present, a likely pathway is shown in Chart 2. The oxidative addition of **1** to nickel, the transfer of an alkyl group from magnesium to nickel, and the reductive elimination of the substituted butenoate from an intermediate **4** should be important elementary reactions, being analogous to those of the corresponding cross-coupling reaction[10] of alkenyl halides with Grignard reagents.

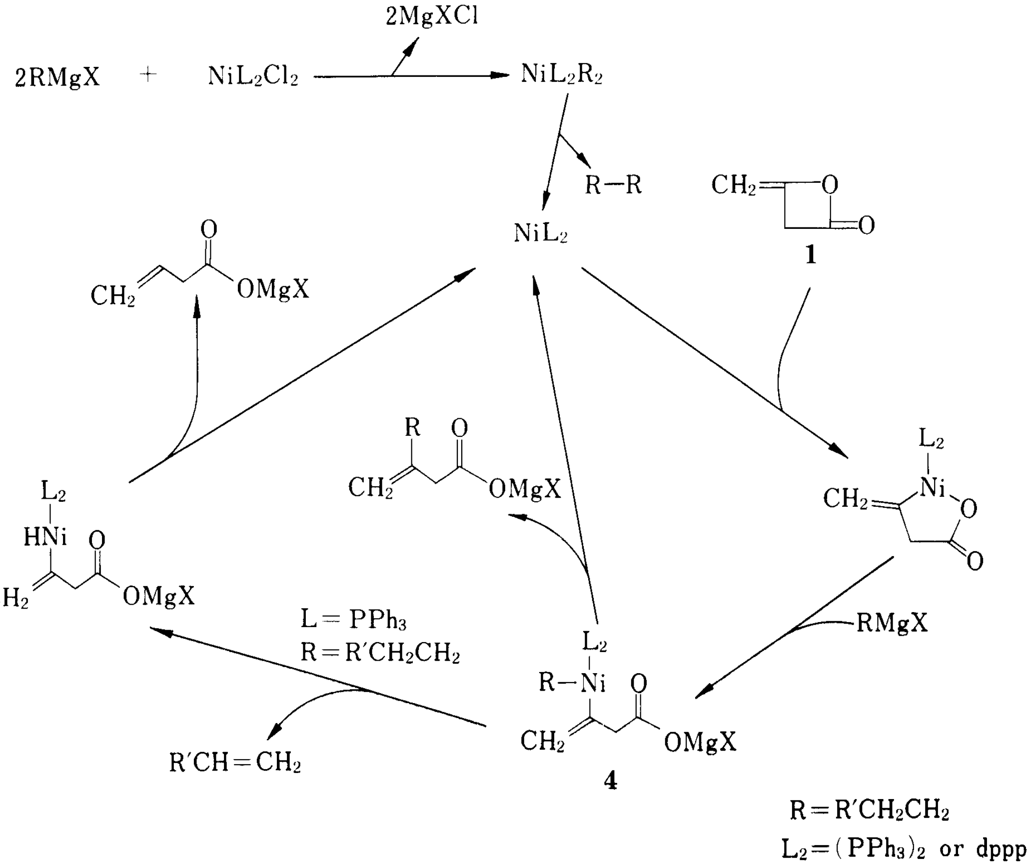


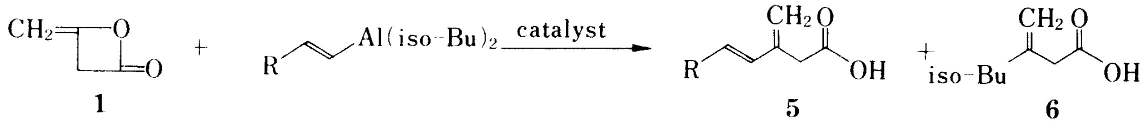
Chart 2

Next, we became interested in the reaction of **1** with organoaluminiums or organozincs, instead of Grignard reagents, because they are known to be easily prepared and less reactive with carbonyl carbon than Grignard reagents.

Recently, it has been reported that the cross-coupling reaction[12] of alkenyl halides with alkenylaluminiums proceeds in the presence of Pd(0)- or Ni(0)-phosphine. Thus, we investigated the reaction of **1** with 1-alkenylaluminiums.

When a solution of (*E*)-1-heptenyldiisobutylaluminium (0.014 mol) was treated with a mixture of **1** (0.01 mol) and tetrakis(triphenylphosphine)nickel [Ni(PPh$_3$)$_4$] (0.0007 mol) in tetrahydrofuran (THF), the desired acid **5a** with retention of the *E* geometry was obtained in 35% yield (run 14). Use of Pd(0)-phosphine catalyst, prepared from bis(triphenylphosphine)palladium dichloride [PdCl$_2$(PPh$_3$)$_2$] and diisobutylaluminium hydride (DIBAH), furnished **5a** in 54% yield, accompanied by a small amount of 5-methyl-3-methylenehexanoic acid (**6**) (run 15). The results of the reaction of **1** with 1-alkenylaluminiums are sum-

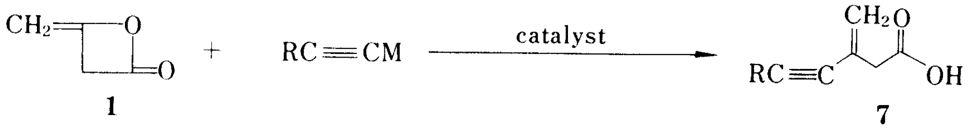
Table III. Reaction of Diketene with Alkenylaluminiums



Run	R	Catalyst[a]	No.	5 Yield (%)	6 Yield (%)
14	C_5H_{11}	A	**5a**	35	0
15	C_5H_{11}	B	**5a**	54	6
16	C_4H_9	A	**5b**	38	0
17	C_4H_9	B	**5b**	51	4
18	C_3H_7	A	**5c**	43	0
19	C_3H_7	B	**5c**	51	4

a) A, $Ni(PPh_3)_4$; B, $PdCl_2(PPh_3)_2$ + DIBAH.

Table IV. Reaction of Diketene (**1**) with Alkynyl Organometallics



Run	RC≡CM	Catalyst[b]	Temp. (°C)	Product	
				No.	Yield (%)
20	$C_5H_{11}C{\equiv}CZnCl$	A	rt[c]	**7a**	52
21	$C_5H_{11}C{\equiv}CZnCl$	B	rt	**7a**	38
22	$C_4H_9C{\equiv}CZnCl$	A	rt	**7b**	37
23	$C_3H_7C{\equiv}CZnCl$	A	rt	**7c**	60
24	$C_6H_5C{\equiv}CZnCl$	A	rt	**7d**	47
25	$C_6H_5C{\equiv}CMgBr$	C	−70	**7d**	0
26	$C_6H_5C{\equiv}CMgBr$	D	−70	**7d**	0
27	$C_6H_5C{\equiv}CCu$[a]	None	rt	**7d**	0

a) Acetonitrile was used as a solvent.
b) A, $Ni(PPh_3)_4$; B, $Pd(PPh_3)_2Cl_2$ + DIBAH; C, $NiCl_2$; D, CoI_2.
c) rt, room temperature.

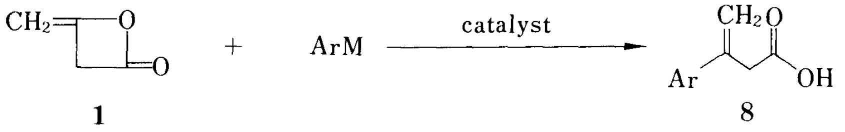
marized in Table III. It was found that Pd(0)-phosphine complex was the more effective catalyst.

Transmetallation to nickel or palladium from alkynyl-[13] or aryl-[14] zinc chloride is known.[15] Negishi *et al.*[13,14] have reported that cross-coupling products are obtained by the Pd(0)- or Ni(0)-catalyzed reaction of alkenyl or aryl halides with these zinc derivatives. Therefore, we examined the reaction of **1** with these organozincs.

When a solution of 1-heptynylzinc chloride, prepared from 1-heptynyllithium and zinc chloride, was treated with a mixture of **1** and $Ni(PPh_3)_4$ in THF, the expected acid **7a** was obtained in 52% yield (run 20). The reaction in the presence of Pd(0)-catalyst furnished **7a** in 38% yield. The results of the reactions with representative 1-alkynyl organometallics are summarized in Table IV. The reaction with 1-alkynylzinc chloride in the presence of $Ni(PPh_3)_4$ gave the best result.

Diketene **1** also reacted with arylzinc chlorides in the presence of Pd(0)- or Ni(0)-catalyst to give the desired acids **8a**—**c** (run 32—35). The reactions with some aryl organometallics are summarized in Table V. Arylzinc chloride in the presence of Pd(0)-catalyst gave the best

Table V. Reaction of Diketene with Aryl Organometallics



Run	ArM	Catalyst[a]	Solvent	Temp. (°C)	Product No.	Product Yield (%)
28	$(C_6H_5)_2CuMgCl$	None	THF–$(CH_3)_2S$	−70	**8a**	0
29	C_6H_5MgBr	A	THF	−70	**8a**	0
30	C_6H_5MgBr	B	Ether	−70	**8a**	2
31	C_6H_5MgBr	C	Ether	−70	**8a**	0
32	C_6H_5ZnCl	D	Ether–THF	rt[b]	**8a**	13
33	C_6H_5ZnCl	E	Ether–THF	rt	**8a**	44
34	*m*-CH_3–C_6H_4ZnCl	E	Ether–THF	rt	**8b**	51
35	*p*-CH_3–C_6H_4ZnCl	E	Ether–THF	rt	**8c**	46

a) A, $NiCl_2$; B, $NiCl_2(PPh_3)_2$; C, $NiCl_2(dppp)$; D, $Ni(PPh_3)_4$; E, $PdCl_2(PPh_3)_2$+DIBAH.
b) rt, room temperature.

result.

In addition, the reaction of **1** with metal hydride was investigated. Diketene (**1**) reacted with DIBAH in the presence of Pd(0)-catalyst to give 3-butenoic acid (**3**) in 17% yield. Compound **3** was also obtained in 22% yield by the Ni-catalyzed reaction of **1** with isobutylzinc chloride.

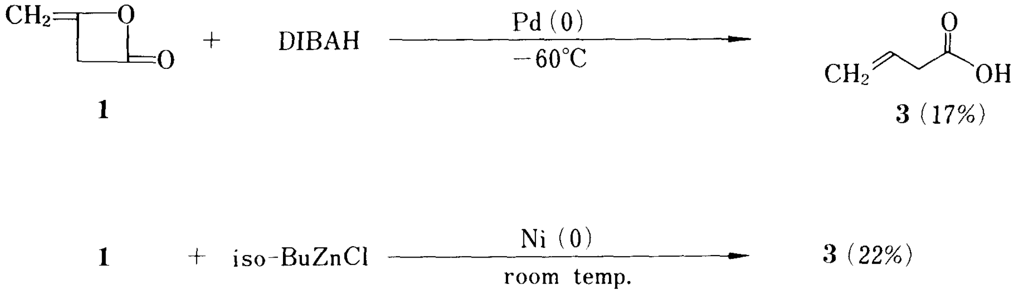


Chart 3

The results of our work show: 1) 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, and metal hydride, in the presence of appropriate Ni- or Pd-catalysts. 2) In view of the ready availability of the catalysts and organometallics and the mildness of the reaction conditions, these reactions will be useful for the preparation of various 3-substituted 3-butenoic acids. 3) There has been a vast amount of work dealing with Ni- or Pd-catalyzed cross-coupling reactions of alkenyl halides with organometallics.[10,15a,16] In contrast, only a few examples are known concerning the similar coupling reaction which involves alkenyl-oxygen bond fission.[7,15a,17] Our work provides additional examples of such reactions.

Experimental

All melting points are uncorrected. $NiCl_2(PPh_3)_2$,[18] $NiCl_2(dppp)$,[19] and $PdCl_2(PPh_3)_2$[20] were prepared according to the literature. The following catalysts and organometallics were prepared *in situ* by known methods: $Ni(PPh_3)_4$,[21] Pd(0)-catalyst,[12] (*E*)-1-alkenyldiisobutylaluminiums,[22] alkynylzinc chlorides,[13] arylzinc chlorides,[14] alkynyllithiums,[23] aryllithiums,[24] and isobutyllithium.[25] Infrared (IR) spectra were taken on a JASCO A-102 spectrometer. Nuclear magnetic resonance (NMR) spectra were recorded on a JEOL JNM-PMX 60 (δ from tetramethylsilane in $CDCl_3$).

General Procedure for the Reaction of Diketene (1) with Organometallics——A (Procedure for Runs 1—5): Nickel chloride (0.387 g, 0.003 mol) was added to a solution of Grignard reagent prepared from a suspension of Mg (4.0 g, 0.167 g atom) in THF (60 ml) and a solution of benzyl halide (0.03 mol) in THF (17 ml). The mixture was stirred for 10 min at room temperature. A solution of **1** (1.68 g, 0.02 mol) in THF (8 ml) was added to this mixture at −70 °C. This reaction mixture was stirred at below −70 °C for 1 h. The reaction was quenched with aq. HCl and the reaction mixture was extracted with ether. The separated organic layer was extracted with aq. $NaHCO_3$. The alkaline solution was acidified with aq. HCl, and then extracted with ether. The ether extracts were dried over $MgSO_4$ and concentrated. The residue was subjected to silica gel column chromatography (hexane–ether) to give **2a**—**e**. Further purification was performed by distillation or recrystallization.

B (Procedure for Runs 9 and 11): Ether (50 ml) and $NiCl_2(PPh_3)_2$ (1.96 g, 0.003 mol) were added sequentially at room temperature to a solution of Grignard reagent prepared from Mg (0.76 g, 0.033 mol) and a solution of alkyl halide (0.03 mol) in ether (30 ml). A solution of **1** in ether (20 ml) was added to this mixture at −70 °C. The whole was stirred for 1 h at below −70 °C. Work-up according to general procedure A afforded **2g**, **i** and **3**.

C (Procedure for Runs 10, 12, and 13): Diketene (**1**), Grignard reagent, and $NiCl_2$(dppp) (1.06 g, 0.002 mol) were treated as described for general procedure B. The mixture was stirred for 3 h. The residue obtained by the usual work-up was purified by distillation to give **2g**—**i**.

D (Procedure for Runs 14, 16, and 18): A 25% hexane solution of DIBAH (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-Alkenyldiisobutylaluminium, prepared from a solution of 1-alkyne (0.015 mol) in hexane (3 ml) and a 25% hexane solution of DIBAH (8.0 ml, 0.014 mol), was added at below −10 °C to this mixture. The mixture was stirred at room temperature for 2.5 h. The acids **5a**—**c** were isolated by work-up as described for general procedure A.

E (Procedure for Runs 15, 17, and 19): The acids **5a**—**c** and **6** were obtained according to general procedure D, using nickel acetylacetonate [$Ni(acac)_2$] (0.19 g, 0.007 mol) and triphenylphosphine (0.73 g, 0.0028 mol) instead of $PdCl_2$ $(PPh_3)_2$.

F (Procedure for Runs 20 and 22—24): A 25% hexane solution of DIBAH (1.6 ml, 0.028 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 this mixture, 1-alkynylzinc chloride [prepared from 1-alkyne (0.015 mol) in THF (15 ml), a 15% solution of butyllithium (8.5 ml, 0.014 mol) and zinc chloride (2.05 g, 0.015 mol)] was added at room temperature. The reaction mixture was stirred at room temperature for 2 h, then quenched with aq. HCl, and most of the THF was evaporated off *in vacuo*. Work-up as described for general procedure A furnished **7a**—**c**.

G (Procedure for Runs 33—35): A 25% hexane solution of DIBAH (1.6 ml, 0.0028 mol) and a solution of **1** (0.84 g, 0.01 mol) in THF (15 ml) were added sequentially to a suspension of $PdCl_2(PPh_3)_2$ (0.98 g, 0.0014 mol) in THF (15 ml). Arylzinc chloride, prepared from a suspension of excess lithium in ether (15 ml), a solution of aryl bromide (0.015 mol) in ether (5 ml) and a solution of zinc chloride (2.18 g, 0.016 mol) in THF (25 ml), was added with ice-cooling to the mixture. The whole was stirred at room temperature for 1 h. Work-up as described for general procedure A afforded **8a**—**c**.

3-Benzyl-3-butenoic Acid (2a) (Run 1)——The acid **2a** was isolated according to general procedure A, using a suspension of Mg (0.74 g, 0.03 g atom) in THF (17 ml) and a solution of benzyl chloride (3.80 g, 0.03 mol) in THF (8 ml). Yield, 1.88 g (53%).

5,5-Dimethyl-3-methylenehexanoic Acid (2f) (Run 6)——Nickel chloride (0.258 g, 0.002 mol) was added at −30 °C to a solution of neopentylmagnesium chloride prepared from Mg (0.48 g, 0.02 g atom) and neopentyl chloride (2.13 g, 0.02 mol) in THF (35 ml). The mixture was stirred at below 0 °C for 45 min. A solution of **1** (1.18 g, 0.014 mol) in THF (5 ml) was added at −75 °C to this mixture. The whole was stirred at −75 °C for 1 h. Work-up as described for general procedure A afforded 0.69 g (31%) of **2f**.

Reaction of 1 with 1-Heptynylzinc Chloride in the Presence of Pd(0)-Catalyst (Run 21)——The acid **7a** was obtained according to general procedure F, using $PdCl_2(PPh_3)_2$ (0.98 g, 0.0014 mol) instead of $Ni(acac)_2$ and triphenylphosphine. Yield, 0.68 g (38%).

Reaction of 1 with Phenylzinc Chloride in the Presence of $Ni(PPh_3)_4$ (Run 21)——The acid **8a** was obtained according to general procedure G, using $Ni(acac)_2$ (0.36 g, 0.0014 mol) and triphenylphosphine (1.47 g, 0.0056 mol) instead of $PdCl_2(PPh_3)_2$. Yield, 0.21 g (13%).

Reaction of 1 with DIBAH in the Presence of Pd(0)-Catalyst——A 25% hexane solution of DIBAH (1.6 ml, 0.0028 mol) and a solution of **1** (0.84 g, 0.01 mol) in THF (15 ml) were sequentially added to a suspension of $PdCl_2(PPh_3)_2$ (0.98 g, 0.0014 mol) in THF (15 ml). A 25% hexane solution of DIBAH (16 ml, 0.028 mol) was added at −60 °C to the mixture. This mixture was stirred at below −60 °C for 1 h. Work-up as described for general procedure A afforded 0.15 g (17%) of 3-butenoic acid (**3**). bp 90 °C (20 mmHg) (lit.[26) bp 169 °C). Compound **3** was identified by comparison of its IR spectrum with that given in the literature.[26)

TABLE VI. Properties and Elemental Analyses

Compd. No.	mp (°C) (Recryst. solvent) or bp (°C)[a] (mmHg)	Analysis (%) Found (Calcd)		IR ($CHCl_3$) cm^{-1}	NMR (δ, J in Hz)
		C	H		
2a	39—40 (Petroleum ether)	75.14 (74.97	6.86 6.86)	1703 (C=O) 1640 (C=C)	3.03 (2H, s, CH_2CO), 3.49 (2H, s, $C\underline{H}_2C_6H_5$), 5.02 (2H, s, $=CH_2$), 7.23 (5H, s, C_6H_5), 10.63 (1H, br, OH)
2b	58—60 (Hexane)	69.72 (69.88	7.04 6.84)	1708 (C=O) 1648 (C=C)	3.02 (2H, s, CH_2CO), 3.43 (2H, s, $C\underline{H}_2C_6H_4$), 3.77 (3H, s, CH_3O), 5.01 (2H, s, $=CH_2$), 6.83 and 7.09 (4H, ABq, $J=8.5$, C_6H_4), 10.82 (1H, br, OH)
2c[b]	43.5—45 (Petroleum ether)	76.55 (76.84	6.89 6.81)	1705 (C=O) 1640 (C=C)	3.06 (2H, s, CH_2CO), 3.50 (2H, s, $C\underline{H}_2C_6H_4$), 3.80 (3H, s, CH_3O), 4.97 (2H, s, $=CH_2$), 6.75—7.45 (4H, m, C_6H_4), 11.40 (1H, br, OH)
2d	39—39.5 (Hexane)	75.46 (75.76	7.40 7.42)	1711 (C=O) 1650 (C=C)	2.30 (3H, s, CH_3), 3.00 (2H, s, CH_2CO), 3.42 (2H, s, $C\underline{H}_2C_6H_4$), 5.00 (2H, s, $=CH_2$), 7.07 (4H, s, $CH_2C_6\underline{H}_4$), 10.10 (1H, br, OH)
2e	110 (0.01)	75.95 (75.76	7.62 7.42)	1700 (C=O) 1640 (C=C)	2.30 (3H, s, CH_3), 2.93 (2H, s, CH_2CO), 3.40 (2H, s, $C\underline{H}_2C_6H_4$), 4.93 (2H, s, $=CH_2$), 6.93 (4H, m, $CH_2C_6\underline{H}_4$), 11.00 (2H, br, OH)
2f	70 (0.5)	69.19 (69.19	10.73 10.32)	1700 (C=O) 1640 (C=C)	0.95 (9H, s, $(CH_3)_3C$), 2.04 (2H, s, $C\underline{H}_2C(CH_3)$)), 3.04 (2H, s, CH_2CO), 5.00 (2H, s, $=CH_2$), 11.13 (1H, br, OH)
2g	100 (2)	67.46 (67.57	10.25 9.93)	1705 (C=O) 1640 (C=C)	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, OH)
2h	80 (2)	63.13 (63.09	8.84 9.07)	1710 (C=O) 1650 (C=C)	1.04 (3H, t, $J=7.0$, CH_3), 2.17 (2H, q, $J=7.0$, $C\underline{H}_2CH_3$), 3.09 (2H, s, CH_2CO), 4.93 (2H, s, $=CH_2$), 10.33 (1H, br, OH)
2i	100 (2)	65.46 (65.59	9.73 9.44)	1705 (C=O) 1640 (C=C)	0.90 (3H, t, $J=6.0$, CH_3), 1.1—1.8 (2H, m, $C\underline{H}_2CH_3$), 2.13 (2H, t, $J=7.5$, $C\underline{H}_2C_2H_5$), 3.07 (2H, s, CH_2CO), 4.93 (2H, s, $=CH_2$), 9.40 (1H, br, OH)
5a	130 (0.1)	72.22 (72.49	10.06 9.96)	1705 (C=O) 900 ($C=CH_2$)	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, $J=17.0$, $J=6.0$, $CH_2C\underline{H}=$), 6.16 (1H, d, $J=17.0$, $=CH-C=$), 9.87 (1H, br, OH)
5b	120 (0.1)	71.19 (71.39	9.57 9.57)	1710 (C=O) 900 ($C=CH_2$)	0.8—2.4 (9H, m, C_4H_9), 3.26 (2H, s, CH_2CO), 5.07 and 5.13 (each 1H, s, $=CH_2$), 5.68 (1H, dt, $J=16.0$, $J=6.0$, $CH_2C\underline{H}=$), 6.17 (1H, d, $J=16.0$, $=CH-C=$), 11.19 (1H, br, OH)
5c	110 (0.08)	69.84 (70.10	9.00 9.15)	1710 (C=O) 900 ($C=CH_2$)	0.88 (3H, t, $J=7.0$, CH_3), 1.1—2.3 (2H, m, $C\underline{H}_2CH_3$), 2.08 (2H, dd, $J=13.0$, $J=6.0$, $C\underline{H}_2C_2H_5$), 5.05 and 5.13 (each 1H, s, $=CH_2$), 5.58 (1H, dt, $J=16.5$, $J=6.0$, $CH_2C\underline{H}=$), 6.18 (1H, d, $J=16.5$, $=CH-C=$), 9.20 (1H, br, OH)
6	70 (0.1)	67.52 (67.57	9.86 9.93)	1705 (C=O) 905 ($C=CH_2$)	0.88 (6H, d, $J=6.0$, CH_3), 1.2—2.2 (3H, m, $CHCH_2$), 3.05 (2H, s, CH_2CO), 4.97 (2H, s, $=CH_2$), 9.83 (1H, br, OH)
7a	165 (0.1)	73.12 (73.30	8.95 8.95)	2220 (C≡C) 1720 (C=O)	0.6—2.6 (11H, m, C_5H_{11}), 3.19 (2H, s, CH_2CO), 5.31 and 5.41 (each 1H, s, $=CH_2$), 10.26 (1H, br, OH)
7b	155 (0.1)	71.87 (72.26	8.34 8.49)	2220 (C≡C) 1715 (C=O)	0.6—2.75 (9H, m, C_4H_9), 3.23 (2H, s, CH_2CO), 5.35 and 5.48 (each 1H, s, $=CH_2$), 10.17 (1H, br, OH)

TABLE VI. (continued)

Compd. No.	mp (°C) (Recryst. solvent) or bp (°C)[a] (mmHg)	Analysis (%) Found (Calcd)		IR ($CHCl_3$) cm^{-1}	NMR (δ, J in Hz)
		C	H		
7c	155 (0.05)	70.66 (71.02	7.97 7.95)	2220 ($C \equiv C$) 1705 ($C=O$)	0.95 (3H, t, $J=7.0$, CH_3), 1.54 (2H, m, $C\underline{H}_2CH_3$), 2.27 (2H, t, $J=7.0$, $CH_2C\equiv$), 3.18 (2H, s, CH_2CO), 5.31 and 5.44 (each 1H, s, $=CH_2$), 9.83 (1H, br, OH)
7d	46—47 (Hexane)	77.09 (77.40	5.54 5.41)	2200 ($C \equiv C$) 1705 ($C=O$)	3.30 (2H, s, CH_2CO), 5.47 and 5.63 (1H, s, $=CH_2$), 7.2—7.7 (5H, m, C_6H_5), 11.19 (1H, br, OH)
8a	46—47 (Hexane)	74.15 (74.05	6.04 6.22)	1710 ($C=O$)	3.50 (2H, s, CH_2CO), 5.21 and 5.54 (each 1H, s, $=CH_2$), 7.2—7.7 (5H, m, C_6H_5), 11.68 (1H, s, OH)
8b	28—29 (Hexane)	74.68 (74.97	6.75 6.86)	1710 ($C=O$)	2.27 (3H, s, CH_3), 3.46 (2H, s, CH_2CO), 5.18 and 5.50 (each 1H, s, $=CH_2$), 6.9—7.4 (4H, m, C_6H_4), 11.23 (1H, s, OH)
8c[c]	113—114 (Hexane)	74.52 (74.97	6.93 6.86)	1710 ($C=O$)	2.43 (3H, s, CH_3), 3.62 (2H, s, CH_2CO), 5.30 and 5.64 (each 1H, s, $=CH_2$), 7.22 and 7.45 (each 2H, ABq, $J=8.0$, C_6H_4), 11.70 (1H, s, OH)

a) All boiling points are given as the bath temperature.
b) Elemental analysis value for the anilide (mp 58—59 °C) are shown.
c) MS *m/e*: Calcd for M^+; 176.0836. obsd; 176.0836. Calcd for $(M+1)^+$; 177.0870. obsd; 177.0865.

Reaction of 1 with Isobutylzinc Chloride in the Presence of $Ni(PPh_3)_4$——Isobutyllithium was prepared at below −10 °C from a solution of isobutyl bromide (1.92 g, 0.014 mol) in ether (4 ml) and a suspension of lithium (0.41 g, 0.059 mol). A 25% hexane solution of DIBAH (1.6 ml, 0.028 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 (20 ml). A solution of isobutylzinc chloride, prepared from isobutyllithium (0.014 mol) and a solution of zinc chloride (1.91 g, 0.014 mol) in THF (20 ml), was added with ice-cooling to the mixture. The whole was stirred at room temperature for 1.5 h. Usual work-up afforded 0.20 g (23%) of **3**.

References and Notes

1) Part CXVII: N. Katagiri, R. Niwa, and T. Kato, *Chem. Pharm. Bull.*, **31**, 2899 (1983).
2) A preliminary report of this work has appeared: Y. Abe, H. Goto, M. Sato, and T. Kato, *Chem. Pharm Bull.*, **31**, 1108 (1983).
3) *a)* T. Kato, *Acc. Chem. Res.*, **7**, 265 (1974); *b)* T. Kato and T. Chiba, *Yuki Gosei Kagaku Kyokai Shi*, **39**, 733 (1981).
4) *Cf. a)* F. Pohl and W. Shmidt, Ger. patent 771652 (1942); *b)* F. Chick and N. Wilsmore, *J. Chem. Soc.*, **93**, 946 (1908); *c)* C. Hurd and J. Abernethy, *J. Am. Chem. Soc.*, **62**, 1147 (1940); *d)* J. C. Sheehan and C. W. Beck, *ibid.*, **77**, 4875 (1955).
5) *Cf. a)* R. N. Lacey, *J. Chem. Soc.*, **1954**, 845; *b)* T. Kato and Y. Yamamoto, *Chem. Pharm. Bull.*, **15**, 1334 (1967); *c)* M. F. Carroll and A. R. Bader, *J. Am. Chem. Soc.*, **75**, 5400 (1953); *d)* S. Hünig, E. Benzing, and K. Hübner, *Chem. Ber.*, **94**, 486 (1961); *e)* T. Kato, T. Chiba, and M. Sato, *Chem. Pharm. Bull.*, **26**, 3877 (1978).
6) *Cf. a)* G. A. Hull, F. A. Daniher, and T. F. Conway, *J. Org. Chem.*, **37**, 1837 (1972); *b)* T. Kato, N. Katagiri, and R. Sato, *Chem. Pharm. Bull.*, **27**, 1176 (1979); *c)* T. Kato, M. Sato, and Y. Kitagawa, *ibid.*, **23**, 365 (1975); *d)* T. Kato, T. Chiba, and S. Tsuchiya, *ibid.*, **28**, 327 (1980).
7) *a)* K. Itoh, M. Fukui, and Y. Kurachi, *J. Chem. Soc., Chem. Commun.*, **1977**, 500; *b)* K. Itoh, T. Yogo, and Y. Ishii, *Chem. Lett.*, **1977**, 103.
8) P. J. Davidson, M. F. Lappert, and R. Pearce, *Acc. Chem. Res.*, **7**, 209 (1974) and references cited therein.
9) P. J. Davidson, M. F. Lappert, and R. Pearce, *Chem. Rev.*, **76**, 219 (1976).
10) K. Tamao, K. Sumitani, Y. Kiso, M. Zembayashi, A. Fujioka, S. Kodama, I. Nakajima, A. Minato, and M. Kumada, *Bull. Chem. Soc. Jpn.*, **49**, 1958 (1976) and references cited therein.

11) T. Fujisawa, T. Sato, Y. Gotoh, M. Kawashima, and T. Kawara, *Bull. Chem. Soc. Jpn.*, **55**, 3555 (1982).

12) S. Baba and E. Negishi, *J. Am. Chem. Soc.*, **98**, 6729 (1976).

13) A. O. King, E. Negishi, F. J. Villani, Jr., and A. Silveria, Jr., *J. Org. Chem.*, **43**, 358 (1978).

14) *a)* A. O. King, N. Okukado, and E. Negishi, *J. Chem Soc., Chem. Commun.*, **1977**, 683; *b)* E. Negishi, A. O. King, and N. Okukado, *J. Org. Chem.*, **42**, 1821 (1977).

15) *a)* E. Negishi, *Acc. Chem. Res.*, **15**, 340 (1982); *b)* K. Ruitenberg, H. Kleijn, C. J. Elsevier, J. Meijer, and P. Vermeer, *Tetrahedron Lett.*, **22**, 1451 (1981).

16) K. Tamao, *Kagaku No Ryoiki*, **32**, 357 (1978) and references cited therein.

17) *a)* S. Komiya, A. Yamamoto, and T. Yamamoto, *Yuki Gosei Kagaku Kyokai Shi*, **38**, 633 (1980); *b)* C. Chuit, H. Felkin, C. Frajerman, G. Roussi, and G. Swierczewski, *J. Chem. Soc., Chem. Commun.*, **1968**, 1604; *c)* K. Takai, K. Osima, and H. Nozaki, *Tetrahedron Lett.*, **21**, 2351 (1980); *d)* M. Sato, K. Takai, K. Oshima, and H. Nozaki, *ibid.*, **22**, 1609 (1981); *e)* E. Wenkert, E. L. Michelotti, and C. S. Swindell, *J. Am. Chem. Soc.*, **101**, 2246 (1979); *f)* T. Hayashi, Y. Katsuro, and M. Kumada, *Tetrahedron Lett.*, **21**, 3915 (1980).

18) F. A. Cotton, O. D. Faut, D. M. L. Goodgame, *J. Am. Chem. Soc.*, **83**, 344 (1961).

19) G. R. van Hecke and W. D. Horrocks, Jr., *Inorg. Chem.*, **5**, 1968 (1966).

20) J. L. Brumeister and F. Basolo, *Inorg. Chem.*, **3**, 1587 (1964).

21) J. J. Levison and S. D. Robinson, "Inorganic Syntheses," Vol. XIII, ed. by F. A. Cotton, McGraw-Hill Book Company, New York, 1972, p. 105.

22) G. Zweifel and R. B. Steele, *J. Am. Chem. Soc.*, **89**, 2754 (1967).

23) A. Suzuki, N. Miyaura, S. Abiko, M. Itoh, H. C. Brown, J. A. Sinclair, and M. M. Midland, *J. Am. Chem. Soc.*, **95**, 3080 (1973).

24) R. G. Jones and H. Gilman, "Organic Reactions," Vol. 6, 2nd ed., John Wiley and Sons, Inc., New York, 1961, p. 353.

25) R. G. Jones and H. Gilman, "Organic Reactions," Vol. 6, 2nd ed., John Wiley and Sons, Inc., New York, 1961, p.352.

26) C. J. Pouchert, "Aldrich Library of Infrared Spectra," 2nd ed., Aldrich Chemical Company, Inc., Milwaukee, 1975, p. 263G.