3604 BULLETIN OF THE CHEMICAL SOCIETY OF JAPAN, VOL. 45, 3604—3607 (1972) [Vol. 45. No. 12

Synthetic Reactions by Complex Catalysts XXVIII. Reaction of β-Propiolactone with Alkyl Halide Caused by Cu_2O-Isonitrile Complex

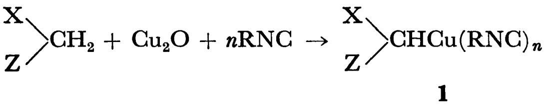
Takeo SAEGUSA, Ichiki MURASE, Michio NAKAI, and Yoshihiko ITO

Department of Synthetic Chemistry, Faculty of Engineering, Kyoto University, Kyoto

(Received April 24, 1972)

Oligomerization of β-propiolactone (BPL) caused by the Cu_2O-isonitrile complex in the presence of alkyl halide was studied, and an oligomeric mixture of acrylate derivatives **3** ($n=1$, 2 and 3 in Eq. (3)) was isolated in fairly high yields. The complex catalyst showed a distinguished catalytic activity for the oligomerization of BPL. The reaction mechanism involving an intermediate of organocopper(I) isonitrile **4**, which is converted into copper(I) acrylate isonitrile complex **5** was presented.

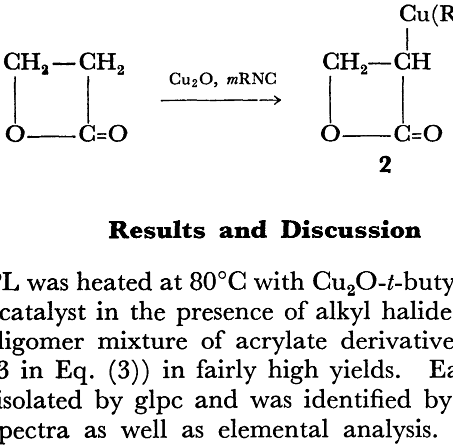
In our continuing studies on the reactions caused by the Cu_2O-isonitrile complex, it has been established[1,2] that the Cu_2O-isonitrile complex abstracts hydrogen atom from the so-called active methylene compound to produce organocopper(I) isonitrile complex **1** which plays a key role as an intermediate in the respective reaction.



$$\begin{matrix}X\\Z\end{matrix}\!\!>CH_2 + Cu_2O + nRNC \rightarrow \begin{matrix}X\\Z\end{matrix}\!\!>CHCu(RNC)_n \quad (1)$$

1

In the present study, β-propiolactone (BPL) was employed as an active hydrogen compound, which was subjected to the reaction with the Cu_2O-isonitrile complex in the presence of alkyl halide. It was found that the Cu_2O-isonitrile complex readily caused oligomerization of BPL, in which oligomers having an acrylic carbon-carbon double bond as the terminal group were selectively produced. It might be of interest to compare with the usual base-catalyzed oligomerization of BPL.[3] For the present oligomerization, a scheme involving an intermediate of organocopper(I) isonitrile complex **2** is presented.

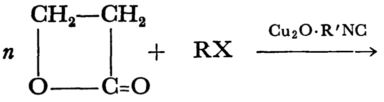


(2)

2

Results and Discussion

BPL was heated at 80°C with Cu_2O-*t*-butyl isocyanide as a catalyst in the presence of alkyl halide to produce an oligomer mixture of acrylate derivatives **3** ($n=1$,2 and 3 in Eq. (3)) in fairly high yields. Each product was isolated by glpc and was identified by NMR and IR spectra as well as elemental analysis. No higher oligomer ($n \geq 4$ of **3**) was detected by glpc analysis.



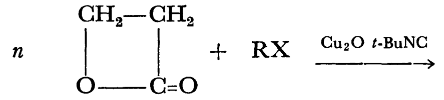
$$CH_2{=}CHCOO(CH_2CH_2COO)_{n-1}\text{-}R \quad (3)$$

3

Some representative reactions are summarized in Table 1.

The reaction of BPL with primary and secondary alkyl halides caused by the Cu_2O-isonitrile system gave the corresponding ester **3**. However, the reaction

TABLE 1. REACTION OF β-PROPIOLACTONE WITH ALKYL HALIDE CAUSED BY THE Cu_2O-*t*-BUTYL ISOCYANIDE[a)]

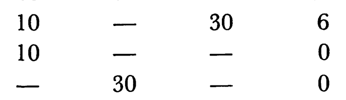


$$CH_2{=}CHCOO(CH_2CH_2COO)_{n-1}\text{-}R$$

Alkyl halide	Product yield (%)[b)]		
	$n=1$	$n=2$	$n=3$
$CH_3O_2CCH_2Cl$	35	26	2
n-BuI	30	27	11
n-BuCl	42	6	1
sec-BuBr	9	29	11
$PhCH_2Br$	15	5	—
$ClCH_2CN$	20	—	—

a) Reaction condition: BPL 20 mmol, alkyl halide 20 mmol, Cu_2O 10 mmol, *t*-BuNC 30 mmol, benzene 5 m*l*, at 80°C, 7 hr. b) Yield is based upon BPL.

TABLE 2. REACTION OF β-PROPIOLACTONE WITH *n*-BUTYL BROMIDE[a)]



$$CH_2{=}CHCOO(CH_2CH_2COO)_{n-1}\text{-}n\text{-}Bu$$

	Catalyst system			Product yield (%)[b)]		
	Cu_2O (mmol)	*t*-BuNC (mmol)	Pyridine (mmol)	$n=1$	$n=2$	$n=3$
1	10	30	—	21	39	9
2	10	—	30	6	26	9
3	10	—	—	0	0	0
4	—	30	—	0	0	0

a) Reaction condition: BPL 20 mmol, *n*-BuBr 20 mmol, benzene 5 m*l* at 80°C, 7 hr. b) Yield is based upon BPL.

---

[1] T. Saegusa, Y. Ito, and S. Tomita, This Bulletin, **45**, 496 (1972).

[2] T. Saegusa, Y. Ito, and S. Tomita, *J. Amer. Chem. Soc.*, **93**, 5656 (1971).

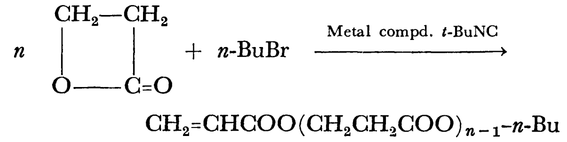
[3] Y. Yamashita, Y. Ishikawa, T. Tsuda, and S. Miura, *Kogyo Kagaku Zasshi*, **66**, 104 (1963).

with *t*-butyl bromide was unsuccessful, since it underwent elimination virtually exclusively under the present reaction conditions, producing isobutene. The reaction with aromatic halide gave no ester derivative.

The Cu_2O-pyridine system also gave rise to oligomerization, although it was somewhat less effective than the Cu_2O-isonitrile system, as seen in Table 2. The presence of Cu_2O was essential. Without Cu_2O, isonitrile alone caused no reaction under the present conditions.

The activities of some copper and silver compounds were examined (Table 3). Cu_2O and Ag_2O in combination with isonitrile showed distinguished results.

TABLE 3. EFFECT OF SOME COPPER AND SILVER COMPOUNDS ON OLIGOMERIZATION OF BPL WITH *n*-BUTYL BROMIDE[a]

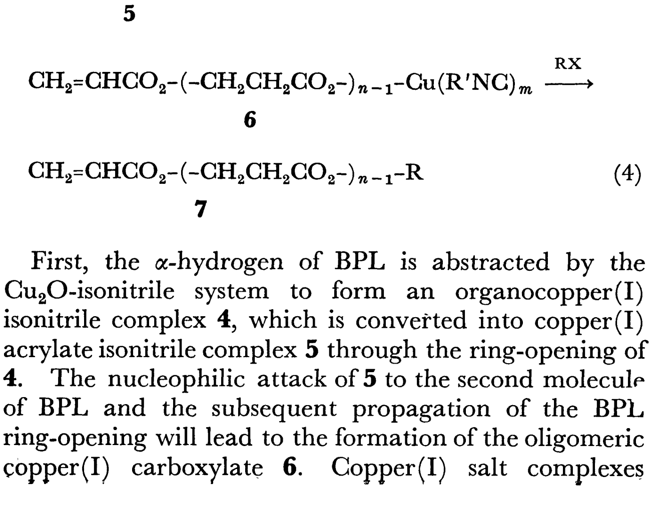


$$n\,\text{BPL} + n\text{-BuBr} \xrightarrow{\text{Metal compd. } t\text{-BuNC}} CH_2{=}CHCOO(CH_2CH_2COO)_{n-1}\text{-}n\text{-Bu}$$

Metal compd.	Product yield (%)[b]		
	$n=1$	$n=2$	$n=3$
Cu_2O	21	39	9
CuO	3	3	Trace
Cu	Trace	3	Trace
CuBr	2	6	Trace
Ag_2O	10	60	18

a) Reaction conditions: BPL 5 mmol, *n*-BuBr 5 mmol, *t*-BuNC 7.5 mmol, metal compound 2.5 mmol, benzene 2.5 m*l*, at 80°C, 7 hr. b) Yield is based upon BPL.

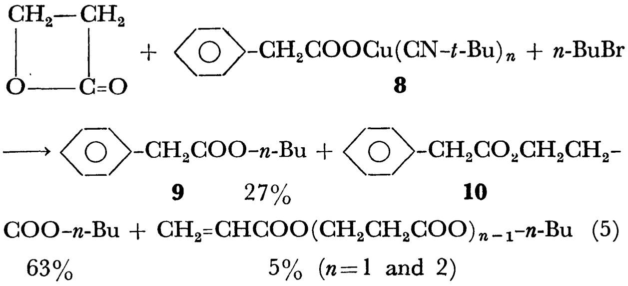
The following scheme explains several experimental findings.



$$CH_2{=}CHCO_2Cu(R'NC)_m\ (\mathbf{5}) \xrightarrow{(n-1)\,\text{BPL}} CH_2{=}CHCO_2\text{-}(\text{-}CH_2CH_2CO_2\text{-})_{n-1}\text{-}Cu(R'NC)_m\ (\mathbf{6}) \xrightarrow{RX} CH_2{=}CHCO_2\text{-}(\text{-}CH_2CH_2CO_2\text{-})_{n-1}\text{-}R\ (\mathbf{7}) \quad (4)$$

First, the α-hydrogen of BPL is abstracted by the Cu_2O-isonitrile system to form an organocopper(I) isonitrile complex **4**, which is converted into copper(I) acrylate isonitrile complex **5** through the ring-opening of **4**. The nucleophilic attack of **5** to the second molecule of BPL and the subsequent propagation of the BPL ring-opening will lead to the formation of the oligomeric copper(I) carboxylate **6**. Copper(I) salt complexes of acrylate and oligomeric carboxylates react with alkyl halide to produce the corresponding esters.

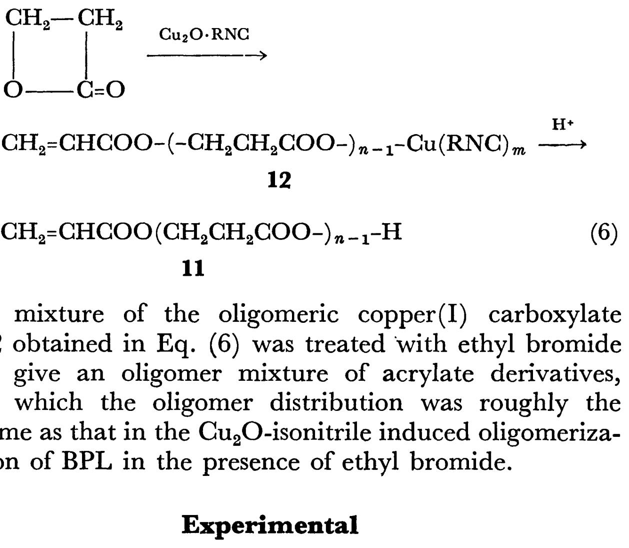
Several findings support the above scheme of the reactions. The nucleophilic attack of copper(I) carboxylate isonitrile complex to BPL was verified by an experiment in which BPL was treated with a complex of copper(I) phenylacetate *t*-butyl isocyanide **8** at 80°C in the presence of *n*-butyl bromide. The products were as follows.



$$\text{BPL} + C_6H_5CH_2COOCu(CN\text{-}t\text{-Bu})_n\ (\mathbf{8}) + n\text{-BuBr} \longrightarrow C_6H_5CH_2COO\text{-}n\text{-Bu}\ (\mathbf{9},\ 27\%) + C_6H_5CH_2CO_2CH_2CH_2COO\text{-}n\text{-Bu}\ (\mathbf{10},\ 63\%) + CH_2{=}CHCOO(CH_2CH_2COO)_{n-1}\text{-}n\text{-Bu}\ (5\%,\ n=1\text{ and }2) \quad (5)$$

Butyl phenylacetate **9** is formed by the direct reaction of **8** with butyl bromide, and **10** is produced by the sequence of reactions of ring-opening of BPL and esterification. The esterification of carboxylic acid with alkyl halide caused by the Cu_2O-isonitrile system has recently been found[4] and may have various applications.

When BPL was treated with the Cu_2O-isonitrile complex in the absence of alkyl halide, a mixture of oligomeric acids ($n=1$, 2 and 3 of **11**) was obtained after work-up with acidic water.



$$\text{BPL} \xrightarrow{Cu_2O\cdot RNC} CH_2{=}CHCOO\text{-}(\text{-}CH_2CH_2COO\text{-})_{n-1}\text{-}Cu(RNC)_m\ (\mathbf{12}) \xrightarrow{H^+} CH_2{=}CHCOO(CH_2CH_2COO\text{-})_{n-1}\text{-}H\ (\mathbf{11}) \quad (6)$$

A mixture of the oligomeric copper(I) carboxylate **12** obtained in Eq. (6) was treated with ethyl bromide to give an oligomer mixture of acrylate derivatives, in which the oligomer distribution was roughly the same as that in the Cu_2O-isonitrile induced oligomerization of BPL in the presence of ethyl bromide.

Experimental

Reagents. Commercial analytical Cu salts and Ag salts were dried under N_2 before use. *t*-Butyl isocyanide was prepared according to Ugi's procedure.[5] Commercial BPL was purified by distillation under nitrogen after being dried over molecular sieves 3A. Commercial alkyl and aryl halides were purified by distillation under nitrogen. Commercial phenylacetic acid of extra pure grade was used.

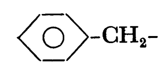
Oligomerization of BPL caused by Cu_2O-t-Butyl Isocyanide in the Presence of n-Butyl Bromide. A mixture of 1.43 g (10 mmol) of Cu_2O, 2.50 g (30 mmol) of *t*-BuNC, 1.45 g

---

[4] T. Saegusa and I. Murase, *Synth. Commun.*, **2**, 1 (1972).

[5] I. Ugi, *Angew. Chem.*, **77**, 492 (1965).

TABLE 4. CHARACTERIZATION OF PRODUCTS
$CH_2{=}CHCOO(CH_2CH_2COO)_{n-1}R$

R	n	Mass (m/e)	Formula	Anal. Calcd % C	Anal. Calcd % H	Anal. Found % C	Anal. Found % H	IR (neat) cm^{-1}	NMR, τ ($CDCl_3$)
n-C_4H_9-	$n=2$	127(P-C_4H_9O) 55($CH_2{=}CHCO$)	$C_{10}H_{16}O_4$	59.98	8.05	59.76	8.37	1740, 1730(C=O) 1640, 1620, 1410(C=C) 1180(C-O)	3.6—4.2(3H, m, $\mathbf{CH_2{=}CH}$-) 5.5(2H, t, =$CHCO_2\mathbf{CH_2}$) 7.25(2H, t, $\mathbf{CH_2}CO_2$-)
	$n=3$	199(P-C_4H_9O) 127 55($CH_2{=}CHCO$)	$C_{13}H_{20}O_6$	57.34	7.40	57.55	7.44	1740(C=O) 1640, 1620, 1410(C=C) 1170(C-O)	3.6—4.3(3H, m, $\mathbf{CH_2{=}CH}$-) 5.55(4H, t, -$COO\mathbf{CH_2CH_2}$-CO) 7.3(4H, t, $\mathbf{CH_2}CO$-)
sec-C_4H_9-	$n=1$		$C_7H_{12}O_2$	65.59	9.44	65.66	9.36	1740(C=O) 1640, 1620(C=O)	3.6—4.3(3H, m, $\mathbf{CH_2{=}CH}$-)
	$n=2$	127(P-C_4H_9O)	$C_{10}H_{16}O_4$	59.98	8.05	60.28	8.23	1735, (C=O) 1640, 1620, 1410(C=C) 1180(C-O)	3.6—4.3(3H, m, $\mathbf{CH_2{=}CH}$-) 5.55(2H, t, =CH-$COO\mathbf{CH_2}$) 7.3(2H, t, $\mathbf{CH_2}CO_2$-)
	$n=3$	199(P-C_4H_9O) 127 55($CH_2{=}CHCO$)	$C_{13}H_{20}O_6$	57.34	7.40	57.02	7.31	1740(C=O) 1640, 1620, 1420(C=C) 1180(C-O)	3.7—4.3(3H, m, $\mathbf{CH_2{=}CH}$-) 5.7(4H, t, $COO\mathbf{CH_2}$-$\mathbf{CH_2}$-CO) 7.45(4H, t, $\mathbf{CH_2}CO$)
C_2H_5-	$n=2$	127(P-C_2H_5O)	$C_8H_{12}O_4$	55.80	7.03	55.97	7.02	1740(C=O) 1640, 1620, 1410(C=C) 1180(C-O)	3.6—4.3(3H, m, $\mathbf{CH_2{=}CH}$-) 5.6(2H, t, =$CHCO_2\mathbf{CH_2}$) 7.4(2H, t, $\mathbf{CH_2}CO$)
	$n=3$	127 55($CH_2{=}CHCO$)	$C_{11}H_{16}O_6$	54.09	6.60	(53.96	6.54)	1740(C=O) 1640, 1620, 1410(C=C) 1180(C-O)	3.6—4.3(3H, $\mathbf{CH_2{=}CH}$-) 5.6(4H, t, $COO\mathbf{CH_2CH_2}CO$) 7.4(4H, t, $\mathbf{CH_2}CO_2$)
CH_3OCOCH_2	$n=1$	144(P) 114(P-CH_3O) 55($CH_2{=}CH\cdot CO$)	$C_6H_8O_4$	50.00	5.60	49.93	5.73	1740, 1770(C=O) 1640, 1620, 1410(C=C) 1160(C-O)	3.5—4.2(3H, m, $\mathbf{CH_2{=}CH}$-) 5.3(2H, s, $CO_2\mathbf{CH_2}CO_2$) 6.2(3H, s, $COO\mathbf{CH_3}$)
	$n=2$	127 55($CH_2{=}CH\cdot CO$)	$C_9H_{12}O_6$	50.00	5.60	49.72	5.65	1730, 1750(C=O) 1640, 1620, 1410(C=C) 1160(C-O	3.5—4.2(3H, m, $\mathbf{CH_2{=}CH}$-) 5.3(2H, s, $CO_2\mathbf{CH_2}CO_2$) 5.5(2H, t, $COO\mathbf{CH_2}CH_2CO$) 6.2(3H, s, $CO_2\mathbf{CH_3}$) 7.1(2H, t, $\mathbf{CH_2}CO$)
	$n=3$	199, 127 55($CH_2{=}CH\cdot CO$)						1740(C=O) 1640, 1620, 1410(C=C) 1160(C-O)	
	$n=1$	162(P) 55($CH_2{=}CHCO$)	$C_{10}H_{10}O_2$	74.05	6.22	74.29	6.50	3025, 1500(ArH) 1730(C=O) 1640, 1620(C=C) 1180(C-O)	2.6(5H, s, ArH) 3.6—4.2(3H, m, $\mathbf{CH_2{=}CH}$-) 4.8(2H, s, $\mathbf{CH_2}Ar$)
$NCCH_2$-	$n=1$	111(P)	$C_5H_5NO_2$	54.05	4.54	54.30	4.60	2250(CN) 1740(C=O) 1640, 1410(C=C) 1170(C-O)	3.5—4.1(3H, m, $\mathbf{CH_2{=}CH}$-) 5.2(2H, s, $O\mathbf{CH_2}CN$)

(20 mmol) of BPL and 2.74 g (20 mmol) of *n*-BuBr in 5 m*l* of benzene was heated under nitrogen with stirring at 80°C for 7 hr. 20 m*l* of petroleum ether was then added and undissolved Cu_2O and precipitated complex were separated by filtration. The filtrate was subjected to distillation, collecting a fraction of 80°C/760 mmHg—110°C/6 mmHg. Each product was purified by means of preparative glpc. Structures of the products were determined by IR and NMR spectra and elemental analysis. The results are summarized in Table 4.

In the case of the other alkyl halides, the reactions were carried out by a similar procedure to that of the reaction with *n*-BuBr under the conditions shown in Tables 1, 2, and 3. The identification data of products are summarized in Table 4.

Reaction of BPL with Copper(I) Phenylacetate t-*Butyl Isocyanide Complex (**8**) in the Presence of* n-*Butyl Bromide.* A mixture of 1.43 g (10 mmol) of Cu_2O, 2.72 g (20 mmol) of phenylacetic acid, and 2.08 g (25 mmol) of *t*-butyl isocyanide in 15 m*l* of benzene was heated at 80°C for 3 hr. Formation of water was observed during the course of the reaction. The reaction mixture was subjected to filtration under nitrogen, and the filtrate was evaporated to remove benzene and water. Cu(I) phenylacetate-*t*-butyl isocyanide complex remained and was dried at 80°C in a vacuum (2 mmHg) for 3 hr. Cu(I) phenylacetate-*t*-butyl isocyanide complex was used for the following reaction without further purification. To this Cu(I) carboxylate *t*-butyl isocyanide complex was added 15 m*l* of benzene and 1.45 g (20 mmol) of BPL and the mixture was heated at 80°C for 3 hr under nitrogen. 20 mmol of *n*-butyl bromide was then added, and the reaction mixture was heated at 80°C for 6 hr. After 20 m*l* of *n*-pentane was added, precipitated CuBr-isonitrile complex was separated. The organic layer was subjected to distillation. *n*-Butyl phenylacetate (**9**) and **10** were obtained in yields of 27% and 63%, respectively. **9**: Found: C, 74.82; H, 8.14%. Calcd for $C_{12}H_{16}O_2$: C, 74.97; H, 8.39%. NMR ($CDCl_3$): τ 2.70 (5H), 6.40 (2H), **10**: Found: C, 68.33; H, 7.65%. Calcd for $C_{15}H_{20}O_4$: C, 68.16; H, 7.63%. NMR ($CDCl_3$): τ 2.71 (5H), 5.69 (2H), 6.39 (2H), 7.38 (2H).

Only small amounts (less than 5%) of acrylate derivatives were identified by comparison of the glpc retention time and the IR spectrum with that of the authentic sample.

*Reaction of Oligomeric Copper(I) Carboxylate (**12**) with Ethyl Bromide.* A mixture of 2.15 g (15 mmol) of Cu_2O, 3.85 g (45 mmol) of *t*-butyl isocyanide and 2.18 g (30 mmol) of BPL in 7.5 m*l* of benzene was heated at 80°C for 5 hr. After the reaction mixture was cooled to room temperature, 4.32 g (40 mmol) of ethyl bromide was added, and the mixture was stirred for 2 hr at room temperature. *n*-Pentane was then added and CuBr-isonitrile complex was separated. The organic layer was subjected to distillation, and the products were purified by preparative glpc. $CH_2{=}CHCOO(CH_2CH_2COO)_{n-1}C_2H_5$ ($n=1$ (10%), $n=2$ (21%), $n=3$ (16%)) was obtained in a total yield of 47%.

When BPL (30 mmol), ethyl bromide (40 mmol), *t*-butyl isocyanide (45 mmol) and Cu_2O (15 mmol) were all mixed together and the mixture was heated at 80°C for 7 hr, almost the same result as above was obtained. The product yields were as follows. $CH_2{=}CHCOO(CH_2CH_2COO)_{n-1}C_2H_5$: $n=1$ (10%), $n=2$ (17%), $n=3$ (8%); Total yield was 35%. Data for the identification of these products are summarized in Table 4.