

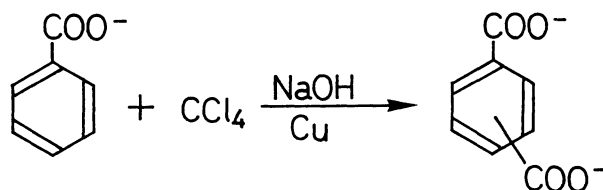
## Carboxylation of Benzoic Acid Using Cyclodextrin as Catalyst

Hidefumi HIRAI\* and Hisashi MIHORI

Department of Industrial Chemistry, Faculty of Engineering,  
Science University of Tokyo, Kagurazaka, Shinjuku-ku, Tokyo 162

Benzoic acid is found to undergo carboxylation by warming with carbon tetrachloride in aqueous alkali in the presence of copper powder with  $\beta$ -cyclodextrin as catalyst. The reaction under mild conditions gives terephthalic acid in good yield with high selectivity.

Carboxylation of phenol by the reaction with carbon tetrachloride in aqueous alkali afforded *o*- and *p*-hydroxybenzoic acids.<sup>1)</sup> Komiyama and Hirai<sup>2,3)</sup> reported that phenol was converted to *p*-hydroxybenzoic acid in 59 mol% yield with 99% selectivity by the use of carbon tetrachloride in aqueous alkali in the presence of copper powder with  $\beta$ -cyclodextrin ( $\beta$ -CyD) as catalyst. The hydroxyl group of phenol has an activating effect on the electrophilic substitution reaction of the aromatic ring. On the other hand, the carboxyl group of benzoic acid has a deactivating effect. The carboxylation of benzoic acid (**1**) using carbon tetrachloride in aqueous alkali has never been reported to our knowledge. In this communication, we wish to report our success in the carboxylation of **1** with carbon tetrachloride in aqueous sodium hydroxide solution by the use of cyclodextrin (CyD) as catalyst.



The following procedures are representative. To 30 mL of 30 wt% aqueous sodium hydroxide solution, 3 mmol of **1**, 0.8 mmol (0.05 g) of copper powder, and 1.5 mmol of  $\beta$ -CyD were added. The reaction was started with the addition of 9.5 mmol of carbon tetrachloride and was continued at 60 °C for 7 h with magnetic stirring under nitrogen. After the reaction was completed, the residual carbon tetrachloride was removed by evaporation under reduced pressure. The cooled reaction mixture was neutralized with hydrochloric acid. The product analysis on the resulting mixture was made by high performance liquid chromatography (HPLC).<sup>4)</sup> The products were identified by comparison with authentic samples (HPLC, MS, and IR). The yields of products are based on starting amount of **1**. The selectivity of terephthalic acid is based on the total amount of carboxylated products.

Figure 1 shows the yields of terephthalic acid (**2**) (para-carboxylated product) and of isophthalic acid (**3**) (meta-carboxylated product) on the carboxylation of **1** with carbon tetrachloride in aqueous sodium hydroxide solution. Formation of phthalic acid (ortho-carboxylated product) was not observed. With increasing amount of  $\beta$ -CyD, the yield of **2** increases and takes a maximum (31 mol% with 95% selectivity) at the initial molar ratio of  $\beta$ -CyD to **1** of 0.5, where the yield of **3** is 1.8 mol%. In the absence of  $\beta$ -CyD, however, the carboxylation did not proceed. When a 2 : 1 ethanol - 30 wt% NaOH aq. solution was used instead of the 30 wt% NaOH aq., the carboxylation occurred without  $\beta$ -CyD but gave only **3** in 1.1 mol% yield. When  $\alpha$ -CyD and  $\gamma$ -CyD were used in the place of  $\beta$ -CyD, the reactions produced only **3** in 0.2 mol% yield and only **2** in 0.3 mol% yield, respectively. Thus, the selective carboxylation of **1** was successfully achieved by using  $\beta$ -CyD as catalyst.

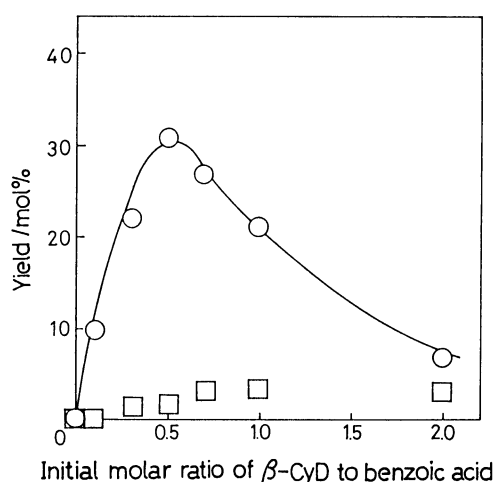


Fig. 1. Dependence of the yields of terephthalic acid (○) and of isophthalic acid (□) on the initial molar ratio of  $\beta$ -CyD to benzoic acid. Conditions: 30 wt% NaOH aq. 30 mL, Cu powder I 0.8 mmol, benzoic acid 3.0 mmol,  $\text{CCl}_4$  9.5 mmol, 60 °C, 7 h.

Figure 2 depicts the plots of the yields of **2** and **3** vs. the initial molar ratio of carbon tetrachloride to **1** in the carboxylation of **1** using  $\beta$ -CyD at the initial molar ratio of 0.5, in the presence of copper powder I<sup>5)</sup> and of copper powder II.<sup>6)</sup> In the case of copper powder I, the yield of **2** takes a maximal value (47 mol% with 92% selectivity) at the initial molar ratio of carbon tetrachloride to **1** of 10, where the yield of **3** was 4.2 mol%. When copper powder II is used instead of the copper powder I, the yield of **2** increases remarkably and has a maximum (74 mol% with 84% selectivity) at the initial molar ratio of carbon tetrachloride to **1** of 50, where the yield of **3** is 14 mol%, as shown in Fig.2.

Figure 3 shows the effect of the amount of copper powder II on the yields of **2** and **3** in the carboxylation of **1** with  $\beta$ -CyD at the molar ratio of 0.5, with carbon tetrachloride at the molar ratio of 50. The yield of **2** has a maximal value (75 mol% with 87% selectivity) at the initial molar ratio of copper powder II to **1** of 0.18, where the yield of **3** was 11 mol%.

In the usual case, the electrophilic substitution reaction of **1** should occur to a small extent at

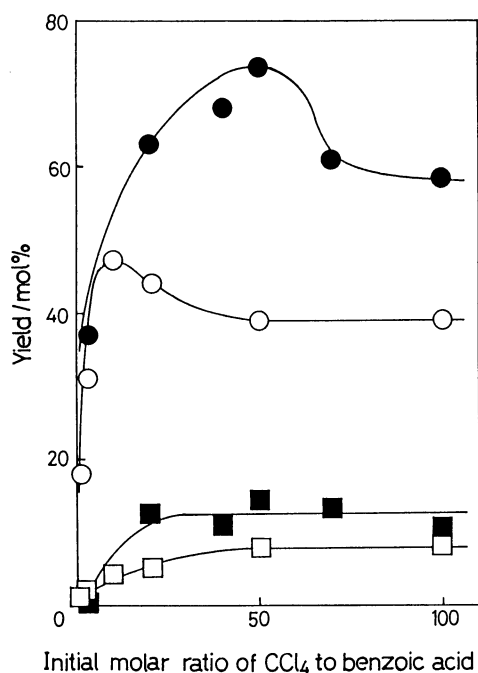


Fig. 2. Plots of the yields of terephthalic acid (○, ●) and of isophthalic acid (□, ■) vs. the initial molar ratio of carbon tetrachloride to benzoic acid: copper powder I (○, □), copper powder II (●, ■). Conditions: 30 wt% NaOH aq. 30 mL, Cu powder I (Cu powder II) 0.8 mmol, benzoic acid 3.0 mmol,  $\beta$ -CyD 1.5 mmol, 60 °C, 7 h.

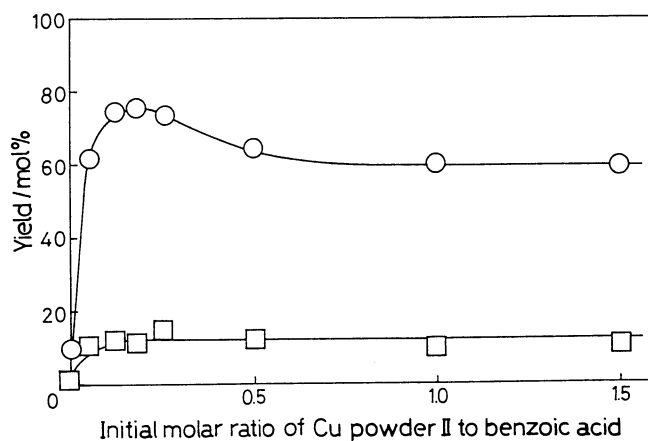


Fig. 3. Dependence of the yields of terephthalic acid (○) and of isophthalic acid (□) on the initial molar ratio of copper powder II. Conditions: 30 wt% NaOH aq. 30 mL, benzoic acid 3.0 mmol, CCl<sub>4</sub> 151 mmol,  $\beta$ -CyD 1.5 mmol, 60 °C, 7 h.

the meta position more than at the para position.

From all these findings, the promotion of the carboxylation by  $\beta$ -CyD is probably attributable to the inclusion complex formation. The solubilities of carbon tetrachloride and **1** in the aqueous alkali in high concentration are increased by the formations of the  $\beta$ -CyD - carbon tetrachloride complex and of the  $\beta$ -CyD - **1** complex. It was reported that carbon tetrachloride molecule fitted

with  $\beta$ -CyD suitably, while the association constants of the  $\alpha$ -CyD - carbon tetrachloride complex and of the  $\gamma$ -CyD - carbon tetrachloride complex were small.<sup>7)</sup> According to the literatures,<sup>8,9)</sup> the carboxyl group of **1** or the carboxylate group of benzoate anion penetrated the CyD cavity from the secondary hydroxyl side of CyD in the process of complex formation. The benzoic acid included in  $\beta$ -CyD may be predominantly attacked at the para position by the active species formed from carbon tetrachloride, aqueous alkali and copper powder. The attacks of the active species at the ortho and meta positions are sterically hindered by the  $\beta$ -CyD including **1**. The active species was proposed to be a trichloromethyl cation.<sup>3)</sup> The decrease in the yield of **2** at the initial molar ratio of  $\beta$ -CyD larger than 0.5 (see Fig.1) may be associated with the deactivation of the active species which is formed too much to react with the benzoic acid in the inclusion complex.

Copper powder II is found to be a better catalyst for yielding **2** (see Fig.2) compared with copper powder I. The high catalytic activity of copper powder II is possibly attributed to the particle size much smaller than that of the copper powder I.

Carbon tetrachloride is required in large excess to get the good yield of **2**, as shown in Fig.2, probably because a considerable part of the active species formed from carbon tetrachloride is decomposed by the reaction with hydroxide ion. The decrease in the yield of **2** at the initial molar ratio of carbon tetrachloride to **1** larger than 50 (see Fig.2) may be due to the following reasons : (1) A large amount of carbon tetrachloride makes the formation of the  $\beta$ -CyD - carbon tetrachloride complex overwhelmingly, preventing that of the  $\beta$ -CyD - **1** complex. (2) The excess carbon tetrachloride dissolves a part of **1**, separating the benzoic acid from the reaction medium.

In summary, the carboxylation of **1** with carbon tetrachloride in aqueous alkali has been achieved by using  $\beta$ -CyD and copper powder II as catalysts, producing **2** in 75 mol% yield with 87% selectivity.

#### References

- 1) K. Reimer and F. Tiemann, *Ber.*, **9**, 1285 (1876).
- 2) M. Komiyama and H. Hirai, *Makromol.Chem., Rapid Commun.*, **2**, 661 (1981).
- 3) M. Komiyama and H. Hirai, *J.Am.Chem.Soc.*, **106**, 174 (1984).
- 4) HPLC conditions : The pH of the mixture was adjusted to 8-9 with the addition of sodium hydrogencarbonate, followed by filtration of the mixture through a sintered glass disk. The filtrate was analyzed by HPLC by using the absorbance at 254 nm ; a strong anion exchange column (TSK-GEL SAX) , 40 °C ; eluent, an aqueous solution of 0.3 M sodium nitrate and 0.05 M boric acid buffer (pH 9.7) with acetonitrile 0-6 (v/v)%.
- 5) Copper, powder (Kanto Chemical Co., extra pure grade) : the average diameter of particles, 125  $\mu$ m.
- 6) Copper, powder, 99%, for organic synthesis (Aldrich Chemical Co.) : the average diameter of particles, 1  $\mu$ m.
- 7) M. Nishimura, T. Deguchi, and I. Sanemasa, *Bull.Chem.Soc.Jpn.*, **62**, 3718 (1989).
- 8) E. Siimer, M. Kurvits, and A. Kstner, *Thermochim. Acta*, **116**, 249 (1987).
- 9) R. J. Bergeron, M. A. Channing, and K. A. McGovern, *J.Am.Chem.Soc.*, **100**, 2878 (1978).

( Received April 27, 1992 )