

## Rare-earth Metal Triflates. An Environment Conscious Catalyst for the chloromethylation of Aromatic Hydrocarbons

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Rare-earth metal triflates, such as Sc(OTf)<sub>3</sub>, Yb(OTf)<sub>3</sub>, Sm(OTf)<sub>3</sub>, In(OTf)<sub>3</sub>, and Hf(OTf)<sub>3</sub> work as effective catalysts for the chloromethylation of aromatic hydrocarbons with hydrochloric acid and trioxane. They are active enough at less than 1.0-5.0 % against substrate under heterogeneous condition of organic and aqueous phases. The triflate stays in aqueous phase after the catalysis, and organic products are easily separated from the catalyst. Sc(OTf)<sub>3</sub> catalyzed chloromethylation of *m*-xylene gave 2,5-bis(chloromethyl)-*m*-xylene with 1,2,4,5-substitution, which is expected to be key intermediate for pyromellitic dianhydride. Biphenyl also gave 4,4'-bis(chloromethyl)biphenyl in good yield.

Key words: Rare-earth metal triflate, chloromethylation, aromatic hydrocarbon, biphasic catalysis

### 1. INTRODUCTION

Fictionalization of aromatic hydrocarbons is key step to advanced materials, and many methods are proposed by many workers. Chloromethylation of aromatic hydrocarbons is one of versatile reactions for these purposes because the chloromethyl group is easily converted to many functional groups.

The chloromethylation of aromatic hydrocarbons has been well documented in the previous papers<sup>1-6</sup>, and sometimes. The reaction occurs by contacting hydrochloric acid and formaldehyde precursor without addition of any catalyst<sup>5,6</sup>, although the rate is slow and not enough for the practical chemical processes. Lewis acids such as zinc chloride, stannic chloride, and boron trifluoride are well known catalysts for the reaction; among these acids, zinc chloride is an effective catalyst in hydrochloric acid solution<sup>1,2</sup>, however, almost stoichiometric amount of the catalyst is required, and makes work-up procedure tedious. It is important to replace these highly corrosive, hazardous and polluting catalysts with environment conscious catalysts which are active under mild conditions, and can be easily recovered after the reactions and reused for the new reactions<sup>7</sup>. Recently, rare-earth metal triflates are active for the catalysis in organic synthesis<sup>8,9</sup>. In this paper, we describe the chloromethylation of aromatic hydrocarbons catalyzed by rare-earth metal triflates.

### 2. EXPERIMENTAL

#### 2.1 Reagents.

Scandium, ytterbium, samarium, indium, and hafnium triflates and other organic chemicals were supplied from Tokyo Kasei Chem. Ind. Co. Ltd., Tokyo. They were used without further purification.

#### 2.2 Reaction procedures.

Typical procedures for the chloromethylation are

shown in the case of *m*-xylene as follows: A mixture of *m*-xylene (I; 1.0 g, 9.4 mmol), trioxane (1.3 g, 14.1 mmol), 35% aqueous hydrochloric acid (4.9 g, 47 mmol), and scandium triflate (50 mg, 0.094 mmol) were stirred in 30 ml round bottom flask for 5 h at 70 °C. After cooling, the organic products were extracted with cyclohexane, and dried over anhydrous sodium sulfate. The solvent was evaporated *in vacuo*, and organic residue was resolved in cyclohexane again, and analyzed by hplc (JASCO, Tokyo, Japan) using Finepack SIL C-18-5 (4.6mm(I.D.)×250mm). The yields of chloromethyl-2,4-dimethylbenzene (II) and 1,5-bis(chloromethyl)-2,4-dimethylbenzene (III) were 73 % and 20 %, respectively. Each product was separated by silica gel column chromatography, and identified by <sup>1</sup>H and <sup>13</sup>C NMR, IR and elemental analysis.

### 3. RESULTS AND DISCUSSION

#### 3.1. Chloromethylation of *m*-xylene

Figure 1 shows the chloromethylation of *m*-xylene (I) with HCl and trioxane as formaldehyde precursor catalyzed by rare-earth metal triflate. The reaction occurred without the catalysts, however, combined yields of chloromethyl-2,4-dimethylbenzene (II) and 1,5-bis(chloromethyl)-2,4-dimethylbenzene (III) was as low as 20 %. Rare-earth metal triflates such as scandium, ytterbium, samarium, indium, and hafnium triflates are enough active in catalytic amounts for the chloromethylation of I to produce II and III. Zinc chloride catalyzed reaction also gave the excellent yields although the stoichiometric amounts are necessary for the high yield. Catalytic activities for the

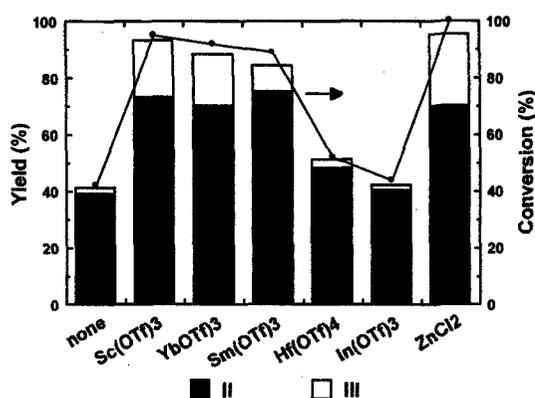


Fig. 1. Chloromethylation of *m*-xylene catalyzed by rare-earth metal triflates. Reaction conditions: rare-earth metal triflate, 0.94 mmol; I, 1 g (9.42 mmol); conc. HCl, 4.9 g (47 mmol); trioxane 0.4 g (4.7 mmol); temperature, 70 °C; period, 5 h.

formation of III decreased in the order: Sc(OTf)<sub>3</sub> ≈ Yb(OTf)<sub>3</sub> ≈ Sm(OTf)<sub>3</sub> > In(OTf)<sub>3</sub> > Hf(OTf)<sub>4</sub>. These catalyses occurred under heterogeneous biphasic conditions: the catalysts were easily separated from the reaction mixtures after the reaction, and recycled for new reaction without loss of the activity.

Figure 2 shows the effects of temperature on the chloromethylation of *m*-xylene catalyzed by Sc(OTf)<sub>3</sub> (trioxane/I=0.5). The yield of II increased with the reaction temperature and reached the maximum at 70 °C. Further raising the reaction temperature resulted in the decrease of the yield of III because of the increase of polychloromethylates of I.

The effect of the amounts of HCl on the chloromethylation at 70 °C is shown in Fig. 3. No reaction occurs in the absence of HCl. The yield of II and III increased with the increase of HCl. The yield was saturated at around 20 % (HCl/I=3). These results

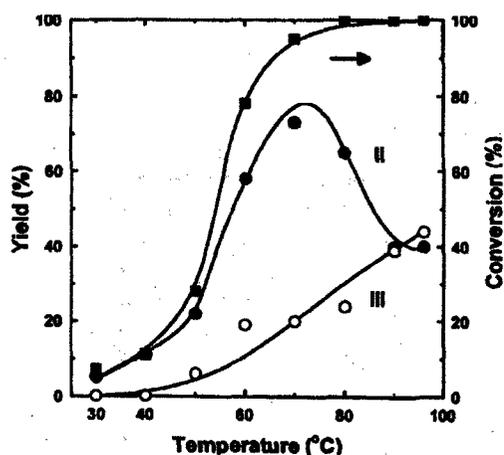


Fig. 2. Effects of reaction temperature on the chloromethylation of *m*-xylene catalyzed by Sc(OTf)<sub>3</sub>. Reaction conditions: Sc(OTf)<sub>3</sub>, 0.05 g (0.094 mmol); *m*-xylene, 1 g (9.4 mmol); conc. HCl, 4.9 g (47 mmol); trioxane 0.4 g (4.7 mmol); period, 5 h.

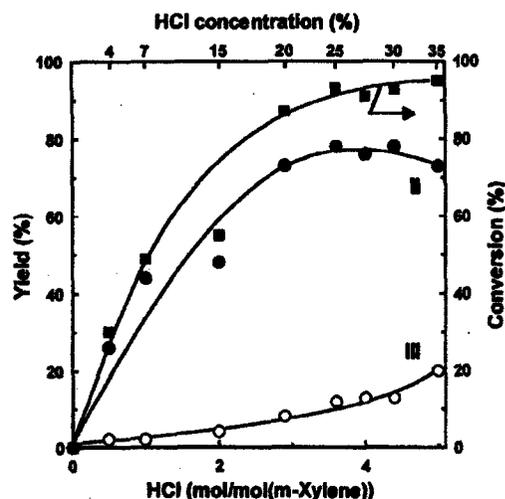


Fig. 3. Effects of amounts of hydrochloric acid on the chloromethylation of *m*-xylene catalyzed by Sc(OTf)<sub>3</sub>. Reaction conditions: Sc(OTf)<sub>3</sub>, 0.05 g (0.094 mmol); I, 1 g (9.4 mmol); conc. HCl, 4.9 g (47 mmol); trioxane 0.4 g (4.7 mmol); temperature, 70 °C; period, 5 h.

show that the amount of HCl is not the principal factor for the catalysis.

Figure 4 shows the effects of amounts of trioxane on the chloromethylation. Catalytic activity increased rapidly with the amounts of trioxane; however, II was the predominant products. Further increase of trioxane enhanced the formation of III, and the yield reached ca. 70 % at CH<sub>2</sub>O/I=4-6. Further increase of trioxane decreased yield of polychloromethylates of I.

Triflate catalysts can be applied for other mononuclear aromatic hydrocarbons, such as benzene, toluene, xylenes, mesitylene, pseudocumene, durene, and pentamethylbenzene to yield chloromethylated products in good to excellent yields under mild conditions such as 70 °C, and at 0.5 of molar ratio of trioxane/aromatic hydrocarbon. The product distributions are similar to the conventional zinc chloride method: the substitution occurred in *o*- and

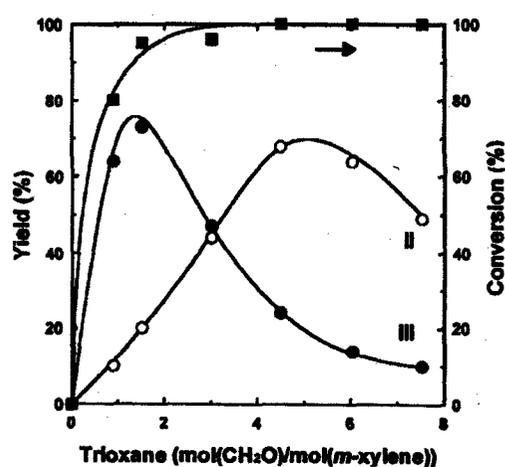


Fig. 4. Effects of the amount of trioxane on the chloromethylation of *m*-xylene catalyzed by Sc(OTf)<sub>3</sub>. Reaction conditions: Sc(OTf)<sub>3</sub>, 0.05 g (0.094 mmol); I, 1 g (9.4 mmol); conc. HCl, 4.9 g (47 mmol); temperature, 70 °C; period, 5 h.

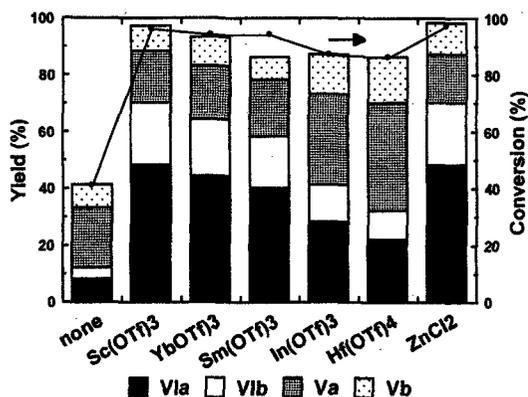


Fig. 5. Chloromethylation of biphenyl catalyzed by rare-earth metal triflates. Reaction conditions: rare-earth metal triflate, 0.48 mmol; I, 1.5 g (9.7 mmol); conc. HCl, 16.4 g (157 mmol); trioxane 6.55 g (72.7 mmol); temperature, 80 °C; period, 22 h.

*p*-directions. Less bulky isomer was predominant, especially, for the monochloromethylation. *p*-Xylene also gave 2,5-bis(chloromethyl)-*p*-xylene 1,2,4,5-substitution in similar manner as I.

### 3.2. Chloromethylation of biphenyl

Figure 5 shows typical results of the chloromethylation of biphenyl (IV) with trioxane and hydrochloric acid by using rare-earth metal triflates. These triflates were highly active for the chloromethylation, and more than 90 % of the conversion was achieved at 80 °C in 22 h to yield 4-chloromethylbiphenyl (Va) and 4,4'-bis(chloromethyl) biphenyl (VIa), however, 2-chloromethylbiphenyl (Vb) and 2,4'-bis(chloromethyl)biphenyl (VIb) accompanied as by-products. Sc(OTf)<sub>3</sub>, Yb(OTf)<sub>3</sub>, and Sm(OTf)<sub>3</sub> have higher activity to form bis(chloromethyl)biphenyls. However, the yield of Va

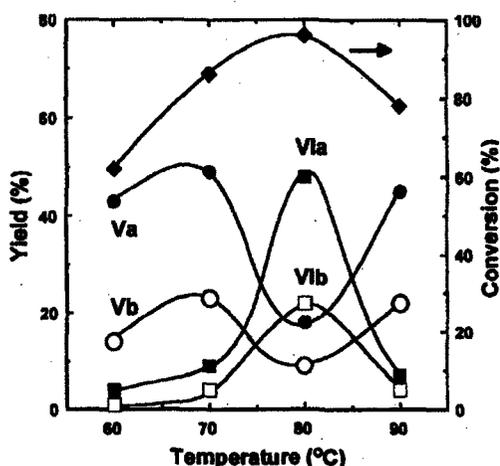


Fig. 6. Effects of temperature on the chloromethylation of biphenyl catalyzed by Sc(OTf)<sub>3</sub>. Reaction conditions: Sc(OTf)<sub>3</sub>, 0.24 g (0.48 mmol); IV, 1.5 g (9.7 mmol); conc. HCl, 16.4 g (157 mmol); trioxane 6.55 g (72.7 mmol); period, 22 h.

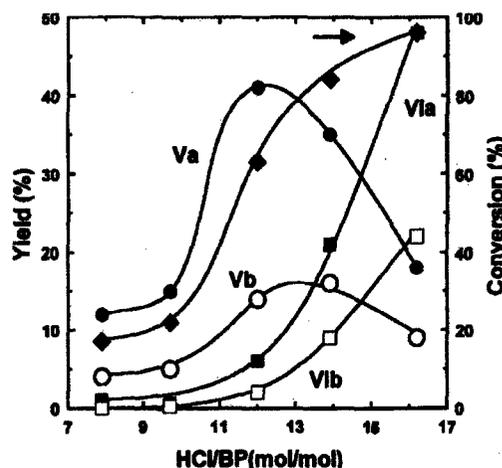


Fig. 7. Effects of the amounts of hydrochloric acid on the chloromethylation of biphenyl catalyzed by Sc(OTf)<sub>3</sub>. Reaction conditions: Sc(OTf)<sub>3</sub>, 0.24 g (0.48 mmol); IV, 1.5 g (9.7 mmol); trioxane 6.55 g (72.7 mmol); temperature, 80 °C; period, 22 h.

decreased in the order: Sc(OTf)<sub>3</sub> > Yb(OTf)<sub>3</sub> > Sm(OTf)<sub>3</sub> > In(OTf)<sub>3</sub> > Hf(OTf)<sub>4</sub>. This is the same order as the case for *m*-xylene. The best yields of Va are 48% for Sc(OTf)<sub>3</sub>. The reaction also occurred without the any catalysts: the conversion was ca. 40 %, and Va was obtained only in 20 % yield. Zinc chloride also gave chloromethylates; however, it is necessary to use stoichiometric amounts. The selectivity for Va was in the same level for all catalysts.

Figure 6 shows effects of temperature for the chloromethylation of IV catalyzed by Sc(OTf)<sub>3</sub>. Catalytic activity increased with the temperature, and reached maximum at 80 °C. Further increase resulted in the decrease of activity. The yield of VIa and VIb reached maxima at 80 °C, and decreased at further high temperature with the increase of the yield of Va and Vb. This decrease of yield is ascribed to the loss of hydrochloric acid at high temperature.

The effects of the amounts of HCl in the chloromethylation of IV catalyzed by Sc(OTf)<sub>3</sub> are shown in Fig. 7. Catalytic activity increased with increasing the amounts of HCl. Va and Vb increased with the increase of HCl. Further addition of HCl enhanced the yield of VIa and VIb with the decrease of Va and Vb.

Figure 8 shows effects of amounts of trioxane in the chloromethylation of IV catalyzed by Sc(OTf)<sub>3</sub>. Catalytic activity increased with the increase of trioxane. First the yield of Va and Vb increased, and further addition enhanced the formation of VIa and VIb. However, addition of excess trioxane resulted in the decrease of VIa because of polychloromethylates of IV.

### 3.3. Chloromethylation of 9,10-dihydrophenanthrene

Figure 9 shows the chloromethylation of 9,10-dihydrophenanthrene (VII) catalyzed by the

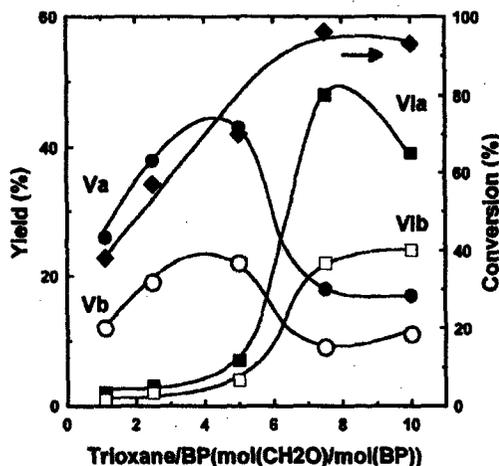


Fig. 8. Effects of the amounts of trioxane on the chloromethylation of biphenyl catalyzed by  $\text{Sc}(\text{OTf})_3$ . Reaction conditions:  $\text{Sc}(\text{OTf})_3$ , 0.24 g (0.48 mmol); **IV**, 1.5 g (9.7 mmol); conc. HCl, 16.4 g (157 mmol); temperature, 80 °C; period, 22 h.

triflates. Triflates enhanced the catalysis to yield 2-chloromethyl-9,10-dihydrophenanthrene (**VIII**) and 2,7-bis(chloromethyl)-9,10-dihydrophenanthrene (**IX**) in high yield. Catalytic activity of triflates are in the order:  $\text{Sc}(\text{OTf})_3 \approx \text{Yb}(\text{OTf})_3 \approx \text{Sm}(\text{OTf})_3 > \text{Hf}(\text{OTf})_4 > \text{In}(\text{OTf})_3$ . This order of activity is similar to the cases of biphenyl and *m*-xylene. The crystallization of **IX** occurred with the progress of the reaction, however, **IX** can be dissolved by the addition of small amount of acetic acid and dioxane. 85% of yield for **IX** was achieved by using  $\text{Sc}(\text{OTf})_3$  by the addition of acetic acid and dioxane.

#### 4. CONCLUSION

Rare-earth metal triflates are highly active for the chloromethylation of various aromatic hydrocarbons. The most important characteristic is only in the catalytic amount of triflates enough for effective chloromethylation. Two or three times amounts of hydrogen chloride against chloromethyl group in the products are enough for reasonable conversion of hydrocarbons. *m*-Xylene, biphenyl, and 9,10-dihydrophenanthrene gave corresponding dichloromethylated products in high yield under mild conditions. These compounds are versatile intermediate chemicals for the advanced materials.

The catalysis by triflates easily occurs in heterogeneous conditions of organic and aqueous phases. Since the triflate stays in aqueous phase during the reaction, the catalyst can be easily separated from the

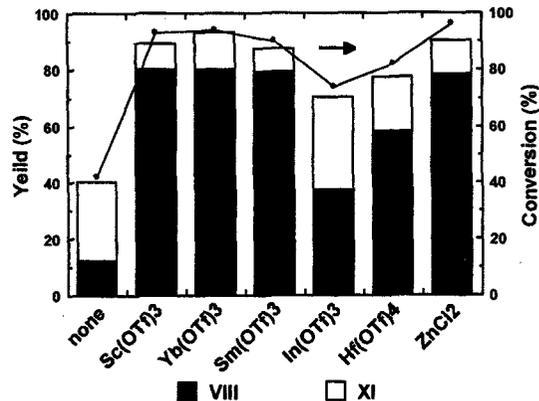


Fig. 9. Chloromethylation of 9,10-dihydrophenanthrene catalyzed by rare-earth metal triflates. Reaction conditions: rare-earth metal triflate, 0.42 mmol; **VII**, 1.5 g (8.3 mmol); conc. HCl, 14.0 g (134 mmol); trioxane 6.6 g (62.2 mmol); temperature, 80 °C; period, 22 h.

products, and recycled again for the reaction. From environmental point of view, rare-earth metal triflates are active enough for the green chloromethylation of aromatic hydrocarbons.

Further aspects of the catalysis and their application to organic synthesis are under investigation.

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