

## Esterification of Aldehydes and Alcohols with Pyridinium Hydrobromide Perbromide in Water

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**Abstract:** The direct esterification of aldehydes and alcohols was carried out with pyridinium hydrobromide perbromide in water at room temperature. A variety of aldehydes were converted to respective ester derivatives with alcohols such as methanol, 1,2-ethanediol, 1,3-propanediol. Further, a variety of aliphatic alcohols were also converted to the corresponding Tishchenko-like dimeric esters in good yields under the same reaction conditions.

**Key words:** esterification, water, pyridinium hydrobromide perbromide, aldehyde, alcohol

Since commercially available ammonium tribromides such as phenyltrimethyl ammonium tribromide (PTAB), pyridinium hydrobromide perbromide (PHPB) are more convenient and safe in maintaining the desired stoichiometry compared to elemental bromine, there has been much interest in an application for a new mild and convenient synthetic method by ammonium tribromides, PTAB, PHPB.<sup>1</sup> PTAB and PHPB have been reported to be useful reagents for brominating the  $\alpha$ -position of carbonyl compounds and for the addition of bromine to alkenes.<sup>2</sup> As the use of PTAB or PHPB is more advantageous and attractive in organic synthesis than that of bromine, it is significant to study other utility of these compounds in organic syntheses. We considered it interesting to find a new procedure for direct esterification of aldehyde and for dimeric esterification of alcohols with PTAB or PHPB.<sup>3</sup> We would like to report on the results of our studies concerning the esterification of various aldehydes and alcohols with PTAB or PHPB.

At first, the esterification of nonanal (**1**), benzaldehyde (**2**), and tolualdehyde (**3**) was carried out with PTAB in MeOH at room temperature, respectively. The results are summarized in Table 1. The reaction of **1** afforded a mixture of methylester **1a** and dimethylacetal **1b** at 4.0 molar equivalents of PTAB over **1** in methanol (run 1). HBr, generated by the decomposition of PTAB, may play a role in the decrease of **1a** under these reaction conditions. The extent of this induced acetalization of **1** can be diminished by the addition of pyridine for neutralizing the acidic conditions. The esterification of **1** was carried out in the presence of pyridine to suppress acetalization of **1**. At the molar ratio of **1**, PTAB, and pyridine (1:4:4), compound **1a** was obtained in good yield without producing **1b** (run

2). To show the effect of PTAB for esterification of **1**, the reaction of **1** was carried out without using PTAB. Nonanal (**1**) was recovered unchanged in 98% yield (run 3). PTAB was consequently ascertained to be essential for the esterification of aliphatic aldehydes in methanol. The esterification of benzaldehyde (**2**) was similarly carried out to examine the chemoselectivity and limitations of this method. At the molar ratio of **2**, PTAB, and pyridine (1:4:4) in methanol, a mixture of methylester **2a** and dimethylacetal **2b** was obtained unexpectedly (run 4). To suppress production of acetal **2b**, the esterification of **2** was carried out in the presence of water. Methylester **2a** was predominantly obtained at the molar ratio of **2**, PTAB, and pyridine (1:4:4) in MeOH–H<sub>2</sub>O (2:1, v/v), but with less satisfactory yield of **2a** (run 5). Benzaldehyde (**2**) was also converted into **2a** accompanied by **2** in MeOH–H<sub>2</sub>O without using pyridine (run 6). Water was supposed to be more useful than pyridine for suppressing acetalization. The esterification of tolualdehyde (**3**) under the same reaction conditions afforded methylester **3a** accompanied by **3**. The yield of **3a** was not fully satisfactory, either run 7. On the contrary, aliphatic methylester **1a** was obtained in good yields in MeOH–H<sub>2</sub>O (run 8). In particular, the less solubility of PTAB in MeOH–H<sub>2</sub>O seemed to be the main reason for obtaining aromatic methylesters **2a** and **3a** in less than 77% yield even for prolonged reaction times (65–90 h).

As pyridinium hydrobromide perbromide (PHPB) is more soluble in water than PTAB, the use of PHPB is expected to be more effective than PTAB for obtaining aromatic methylesters **2a** and **3a** quantitatively. The esterification of **2**, and **3** was carried out with large excess molar amounts of methanol over **2**, and **3** by PHPB in water. The results are summarized in Table 2. In the presence of methanol, compound **2** was converted into **2a** in good yield at room temperature (run 1). Tolualdehyde (**3**) was also converted to **3a** under the same reaction conditions (run 2). In addition, on treatment of **2** with PHPB at 16 molar equivalents of ethylene glycol, hydroxyester **2c** was obtained (run 3). Hydroxyester **3c** was also afforded in good yield (run 4). The esterification of **2** and **3** with PHPB in the presence of 1,3-propanediol took place to give the corresponding hydroxyesters **2d** and **3d** similarly (runs 5, 6). On the other hand, 4-methylbenzoic acid was recovered unchanged under the same reaction conditions.<sup>4</sup> The mechanism for the esterification of aldehyde in the presence of alcohol by PHPB–H<sub>2</sub>O was presumed to be different from the usual manner of the catalytic acidic

**Table 1** Esterification of Aldehydes with PTAB in Methanol<sup>a</sup>

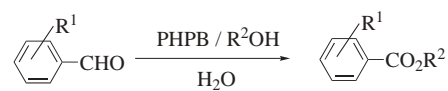
$$\text{R}^1\text{CHO} \xrightarrow[\text{MeOH}]{\text{PTAB}} \text{R}^1\text{CO}_2\text{Me}$$

Run	Substrate R <sup>1</sup>	S	Molar ratio of S		Time (h)	Solvent	Product(s), yield (%)	Product(s), yield (%) <sup>b</sup>
			PTAB	pyridine				
1	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>7</sub>	<b>1</b>	4.0	–	14	MeOH	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>7</sub> CO <sub>2</sub> Me <b>1a</b> , 29	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>7</sub> CH(OMe) <sub>2</sub> <b>1b</b> , 55
2	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>7</sub>	<b>1</b>	4.0	4.0	13	MeOH	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>7</sub> CO <sub>2</sub> Me <b>1a</b> , 84	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>7</sub> CH(OMe) <sub>2</sub> <b>1b</b> , trace
3	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>7</sub>	<b>1</b>	–	4.0	13	MeOH	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>7</sub> CO <sub>2</sub> Me <b>1a</b> , 0 <sup>d</sup>	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>7</sub> CH(OMe) <sub>2</sub> <b>1b</b> , 0
4	Ph	<b>2</b>	4.0	4.0	18	MeOH	PhCO <sub>2</sub> Me <b>2a</b> , 30 <sup>e</sup>	PhCH(OMe) <sub>2</sub> <b>2b</b> , 34
5	Ph	<b>2</b>	4.0	4.0	89	MeOH–H <sub>2</sub> O <sup>c</sup>	PhCO <sub>2</sub> Me <b>2a</b> , 60 <sup>f</sup>	PhCH(OMe) <sub>2</sub> <b>2b</b> , 9
6	Ph	<b>2</b>	4.0	–	90	MeOH–H <sub>2</sub> O <sup>c</sup>	PhCO <sub>2</sub> Me <b>2a</b> , 77 <sup>g</sup>	
7	4-CH <sub>3</sub> Ph	<b>3</b>	4.0	–	65	MeOH–H <sub>2</sub> O <sup>c</sup>	4-CH <sub>3</sub> PhCO <sub>2</sub> Me <b>3a</b> , 71 <sup>h</sup>	
8	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>7</sub>	<b>1</b>	4.0	–	20	MeOH–H <sub>2</sub> O <sup>c</sup>	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>7</sub> CO <sub>2</sub> Me <b>1a</b> , 87	

<sup>a</sup> Substrate (S): 0.25 mmol; MeOH: 8 mL.<sup>b</sup> Isolated yield.<sup>c</sup> v/v = 2:1.<sup>d</sup> Recovered **1**: 98%.<sup>e</sup> Recovered **2**: 33%.<sup>f</sup> Recovered **2**: 30%.<sup>g</sup> Recovered **2**: 22%.<sup>h</sup> Recovered **3**: 27%.

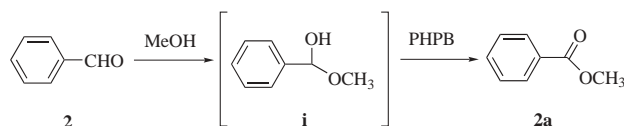
conditions for the esterification of carboxylic acid and alcohol.<sup>5</sup> The above mentioned observations suggested that the esterification of **2** with PHPB–H<sub>2</sub>O proceeded as follows illustrated in Scheme 1. First, the hemiacetalization

of **2** took place to give **i** and then **i** was oxidized to **2a**. This hemiacetalization and oxidation step is proposed to enable for a feasible esterification route (**2** → **i** → **2a**).

**Table 2** Esterification of Aromatic Aldehydes **2**, **3** and Alcohols with PHPB in Water<sup>a</sup>

Run	Substrate R <sup>1</sup>	S	Molar ratio of S		R <sup>2</sup> OH	Time (h)	Product	Yield (%) <sup>b</sup>
			PHPB	R <sup>2</sup> OH				
1	H	<b>2</b>	4.0	125	MeOH	87	PhCO <sub>2</sub> CH <sub>3</sub>	<b>2a</b> , 94
2	4-CH <sub>3</sub>	<b>3</b>	4.0	125	MeOH	70	4-CH <sub>3</sub> PhCO <sub>2</sub> CH <sub>3</sub>	<b>3a</b> , 92
3	H	<b>2</b>	4.0	16	HO(CH <sub>2</sub> ) <sub>2</sub> OH	13	PhCO <sub>2</sub> (CH <sub>2</sub> ) <sub>2</sub> OH	<b>2c</b> , 81
4	4-CH <sub>3</sub>	<b>3</b>	4.0	16	HO(CH <sub>2</sub> ) <sub>2</sub> OH	46	4-CH <sub>3</sub> PhCO <sub>2</sub> (CH <sub>2</sub> ) <sub>2</sub> OH	<b>3c</b> , 89
5	H	<b>2</b>	3.0	8	HO(CH <sub>2</sub> ) <sub>3</sub> OH	45	PhCO <sub>2</sub> (CH <sub>2</sub> ) <sub>3</sub> OH	<b>2d</b> , 85
6	4-CH <sub>3</sub>	<b>3</b>	2.0	1.6	HO(CH <sub>2</sub> ) <sub>3</sub> OH	16	4-CH <sub>3</sub> PhCO <sub>2</sub> (CH <sub>2</sub> ) <sub>3</sub> OH	<b>3d</b> , 89

<sup>a</sup> Substrate (S): 0.25 mmol; H<sub>2</sub>O: 8 mL.<sup>b</sup> Isolated yield.



Scheme 1

The esterification of a variety of aldehydes and alcohols was carried out to elucidate the limitations of the PHPB–H<sub>2</sub>O system. The results are shown in Table 3. Nonanal (**1**) also afforded methylester **1a** in good yield with MeOH by PHPB–H<sub>2</sub>O (run 1). With 1-decanol, **1** was converted into the corresponding ester **1c** (run 2). Isobutyraldehyde (**4**) afforded ester **4a** even with 1-dodecanol (run 3). Hydroxyester derivatives **5a–8a** were also obtained in high yields on treatment of aromatic aldehydes **5–8** in the presence of ethylene glycol with PHPB–H<sub>2</sub>O (runs 4–7). As there have been many organic compounds containing hydroxyester moieties in natural products, this simple PHPB–H<sub>2</sub>O system is expected to be a useful method for the synthesis of natural products.<sup>6</sup> With 2,2-dimethyl-1,3-

propanediol, 4-bromobenzaldehyde (**9**) afforded hydroxyester **9a** in good yield (run 8). On the other hand, aliphatic aldehyde **1** afforded a mixture of hydroxyester **1d** and diester **1e** with 32 molar equivalents of ethylene glycol over **1** (run 9). Therefore, it was assumed that diester derivatives were easily obtained at a small excess of diol over aldehyde. The diesterification of **3** was carried out at a molar equivalent of 1,3-propanediol over **3** with PHPB–H<sub>2</sub>O. Unfortunately, a mixture of diester **3e** and hydroxyester **3d** was obtained (run 10). To clarify the reason for the production of hydroxyester experimentally, the esterification of **3** was carried out with 1,3-butanediol and 1,2-octanediol. A mixture of hydroxyesters **3f**, **3g** and **3h**, **3i** was afforded, respectively (runs 11, 12). Though, secondary alcohols have already been known to be oxidized to give the corresponding ketones by PHPB–H<sub>2</sub>O,<sup>7</sup> β-ketoester derivatives were not produced. It was supposed that the hemiacetal was successively generated as one of the intermediates derived from hydroxyester. Hydroxyesters **3f** and **3i** were consequently obtained without oxidizing secondary hydroxy groups to ketones.

Table 3 Esterification of Aldehydes and Alcohols with PHPB in Water<sup>a</sup>

R <sup>1</sup> CHO		PHPB / R <sup>2</sup> OH		R <sup>1</sup> CO <sub>2</sub> R <sup>2</sup>			
		H <sub>2</sub> O					
Run	Substrate R <sup>1</sup>	S	Molar ratio of S		Time (h)	Product(s)	Yield (%) <sup>b</sup>
			PHPB	R <sup>2</sup> OH			
1	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>7</sub>	<b>1</b>	4.0	MeOH	(125)	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>7</sub> CO <sub>2</sub> CH <sub>3</sub>	<b>1a</b> , 89
2	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>7</sub>	<b>1</b>	4.0	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>9</sub> OH	(1.1)	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>7</sub> CO <sub>2</sub> (CH <sub>2</sub> ) <sub>9</sub> CH <sub>3</sub>	<b>1c</b> , 90
3		<b>4</b>	2.0	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>11</sub> OH	(1.1)		<b>4a</b> , 84
4	2-CH <sub>3</sub> Ph	<b>5</b>	4.0	HO(CH <sub>2</sub> ) <sub>2</sub> OH	(16)	2-CH <sub>3</sub> PhCO <sub>2</sub> (CH <sub>2</sub> ) <sub>2</sub> OH	<b>5a</b> , 89
5	3-CH <sub>3</sub> Ph	<b>6</b>	4.0	HO(CH <sub>2</sub> ) <sub>2</sub> OH	(16)	3-CH <sub>3</sub> PhCO <sub>2</sub> (CH <sub>2</sub> ) <sub>2</sub> OH	<b>6a</b> , 84
6	4-ClPh	<b>7</b>	4.0	HO(CH <sub>2</sub> ) <sub>2</sub> OH	(16)	4-ClPhCO <sub>2</sub> (CH <sub>2</sub> ) <sub>2</sub> OH	<b>7a</b> , 94
7	3-ClPh	<b>8</b>	4.0	HO(CH <sub>2</sub> ) <sub>2</sub> OH	(16)	3-ClPhCO <sub>2</sub> (CH <sub>2</sub> ) <sub>2</sub> OH	<b>8a</b> , 87
8	4-BrPh	<b>9</b>	3.0		(6)	4-BrPhCO <sub>2</sub>	<b>9a</b> , 83
9	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>7</sub>	<b>1</b>	4.0	HO(CH <sub>2</sub> ) <sub>2</sub> OH	(32)	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>7</sub> CO <sub>2</sub> (CH <sub>2</sub> ) <sub>2</sub> OH CH <sub>3</sub> (CH <sub>2</sub> ) <sub>7</sub> CO <sub>2</sub> (CH <sub>2</sub> ) <sub>2</sub> OCO(CH <sub>2</sub> ) <sub>7</sub> CH <sub>3</sub>	<b>1d</b> , 42 <b>1e</b> , 53
10	4-CH <sub>3</sub> Ph	<b>3</b>	4.0	HO(CH <sub>2</sub> ) <sub>3</sub> OH	(1.0)	4-CH <sub>3</sub> PhCO <sub>2</sub> (CH <sub>2</sub> ) <sub>3</sub> OH 4-CH <sub>3</sub> PhCO <sub>2</sub> (CH <sub>2</sub> ) <sub>3</sub> OCOPh-4-CH <sub>3</sub>	<b>3d</b> , 43 <b>3e</b> , 36
11	4-CH <sub>3</sub> Ph	<b>3</b>	4.0		(11)	4-CH <sub>3</sub> PhCO <sub>2</sub>	<b>3f</b> , 53
						4-CH <sub>3</sub> PhCO <sub>2</sub>	<b>3g</b> , 33
12	4-CH <sub>3</sub> Ph	<b>3</b>	4.0		(3)	4-CH <sub>3</sub> PhCO <sub>2</sub>	<b>3h</b> , 70
						4-CH <sub>3</sub> PhCO <sub>2</sub>	<b>3i</b> , 24

<sup>a</sup> Substrate (S): 0.25 mmol; H<sub>2</sub>O: 8 mL.

<sup>b</sup> Isolated yield.

On the contrary, diester derivatives were expected to be obtained by the esterification of hydroxyesters and aldehydes with PHPB–H<sub>2</sub>O. The esterification of various hydroxyesters and aldehydes was carried out under the same reaction conditions. The results are shown in Table 4. Hydroxyester **2d** was converted to the corresponding diesters **2g–i** with nonanal, and tolualdehyde, and 2-chlorobenzaldehyde (runs 1–3). Hydroxyester **3d** was also converted to the corresponding diesters **3f–i** with nonanal, benzaldehyde, tolualdehyde, and 2-chlorobenzaldehyde (runs 4–7). As it is often required to transform aldehydes directly into monoesters, diesters, and hydroxyesters during various steps in the synthesis of natural products, the system PHPB–H<sub>2</sub>O provides a significant alternative method for the direct esterification of aldehydes with alcohols.<sup>8</sup>

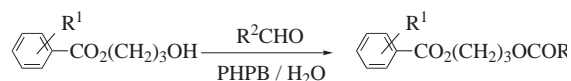
On the other hand, the Tishchenko reaction has been well recognized as a useful method for dimerization of aldehydes, giving the corresponding esters, while few methods for obtaining direct Tishchenko-like dimeric esters of alcohols have been examined.<sup>3k,9–13</sup> The dimeric esterification of various alcohols was subsequently carried out with PHPB–H<sub>2</sub>O.

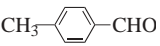


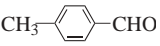

At first, the esterification of straight-chain aliphatic primary alcohols to Tishchenko-like dimeric esters was carried out with PHPB in water. The results are shown in Table 5. Hexanol (**10**) was converted to Tishchenko-like dimeric ester **10a** in nearly quantitative yield at 2.0 molar equivalents of PHPB over **10** in water at room temperature (run 1). The esterification of long-chain aliphatic alcohols, decanol (**11**) and dodecanol (**12**) also afforded dimeric esters **11a** and **12a** in good yields, respectively (runs 2, 3). Even in the presence of methanol, dodecanol

(**12**) was converted into dimeric ester **12a** (run 4). Methyl carboxylate **12b** was not obtained in good yield by intermolecular esterification. With large amounts of MeOH and in long reaction times, Tishchenko-like dimeric ester **12a** was mainly afforded by the reaction of **12** with PHPB–H<sub>2</sub>O (run 5). Further, **12** was transformed to dimeric ester **12a** under the same reaction conditions in the presence of ethylene glycol (run 6). In addition, **11** was converted into dimeric ester **11a** in high yield even in the presence of acetic acid (run 7). It was suggested that the esterification of carboxylic acids with aliphatic alcohols was slower than the dimeric esterification of alcohols by PHPB–H<sub>2</sub>O.

The reaction of various aliphatic primary alcohols under the same reaction conditions was carried out to elucidate the limitations and chemoselectivity for the dimeric esterification by PHPB–H<sub>2</sub>O. The results are shown in Table 6. The reaction of branched-chain aliphatic alcohols **13–15** afforded the corresponding dimeric esters **13a–15a** in good yields as well as straight-chain aliphatic ones **10–12** (runs 1–3). Cyclic aliphatic alcohols **16** and **17** were also converted to the respective dimeric esters **16a** and **17a** in high yields (runs 4, 5). The reaction of 2-ethyl-1,3-hexanediol (**18**) containing both primary and secondary hydroxyl groups took place to give hydroxyketone **19** with PHPB–H<sub>2</sub>O for 75 hours at room temperature. It can be assumed that the oxidation of secondary alcohols to ketones progresses faster than the dimeric esterification of primary ones to ester derivatives with PHPB–H<sub>2</sub>O. In the present experiments, the PHPB–H<sub>2</sub>O system was supposed to be an excellent method for converting aliphatic primary alcohols into Tishchenko-like dimeric esters.

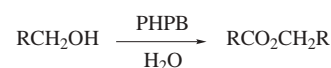
**Table 4** Esterification of Aromatic Hydroxyesters and Aldehydes with PHPB in Water<sup>a</sup>



Run	Substrate R <sup>1</sup>	S	Molar ratio/S		Time (h)	Product	Yield (%) <sup>b</sup>
			PHPB	R <sup>2</sup> CHO			
1	H	<b>2d</b>	2.5	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>7</sub> CHO	24	PhCO <sub>2</sub> (CH <sub>2</sub> ) <sub>3</sub> OCO(CH <sub>2</sub> ) <sub>7</sub> CH <sub>3</sub>	<b>2g</b> , 92
2	H	<b>2d</b>	2.0		25	PhCO <sub>2</sub> (CH <sub>2</sub> ) <sub>3</sub> OCOPh-4-CH <sub>3</sub>	<b>2h</b> , 95
3	H	<b>2d</b>	2.5		48	PhCO <sub>2</sub> (CH <sub>2</sub> ) <sub>3</sub> OCOPh-2-Cl	<b>2i</b> , 88
4	4-CH <sub>3</sub>	<b>3d</b>	2.5	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>7</sub> CHO	13	4-CH <sub>3</sub> -PhCO <sub>2</sub> (CH <sub>2</sub> ) <sub>3</sub> OCO(CH <sub>2</sub> ) <sub>7</sub> CH <sub>3</sub>	<b>3g</b> , 88
5	4-CH <sub>3</sub>	<b>3d</b>	2.5		19	4-CH <sub>3</sub> -PhCO <sub>2</sub> (CH <sub>2</sub> ) <sub>3</sub> OCOPh	<b>3h</b> , 84
6	4-CH <sub>3</sub>	<b>3d</b>	2.5		19	4-CH <sub>3</sub> -PhCO <sub>2</sub> (CH <sub>2</sub> ) <sub>3</sub> OCOPh-4-CH <sub>3</sub>	<b>3f</b> , 92
7	4-CH <sub>3</sub>	<b>3d</b>	2.5		25	4-CH <sub>3</sub> -PhCO <sub>2</sub> (CH <sub>2</sub> ) <sub>3</sub> OCOPh-2-Cl	<b>3i</b> , 93

<sup>a</sup> Substrate (S): 0.25 mmol; R<sup>2</sup>CHO: 1.1 equiv/S; H<sub>2</sub>O: 8 mL.

<sup>b</sup> Isolated yield.

**Table 5** Esterification of Aliphatic Primary Alcohols with PHPB in Water<sup>a</sup>

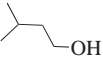
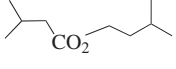
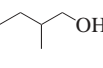
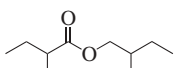
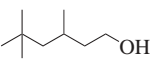
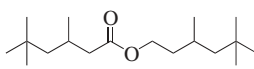
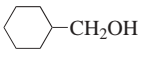
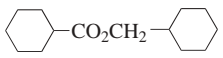
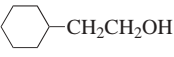

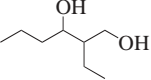
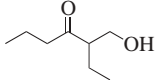
Run	Substrate	S	ROH or RCOOH Molar ratio/S	Time (h)	Product(s)	Yield (%) <sup>b</sup>
1	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>5</sub> OH	<b>10</b>	–	16	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>4</sub> CO <sub>2</sub> (CH <sub>2</sub> ) <sub>5</sub> CH <sub>3</sub>	<b>10a</b> , 98
2	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>9</sub> OH	<b>11</b>	–	14	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>8</sub> CO <sub>2</sub> (CH <sub>2</sub> ) <sub>9</sub> CH <sub>3</sub>	<b>11a</b> , 92
3	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>11</sub> OH	<b>12</b>	–	13	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>10</sub> CO <sub>2</sub> (CH <sub>2</sub> ) <sub>11</sub> CH <sub>3</sub>	<b>12a</b> , 95
4	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>11</sub> OH	<b>12</b>	MeOH 12	13	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>10</sub> CO <sub>2</sub> (CH <sub>2</sub> ) <sub>11</sub> CH <sub>3</sub> CH <sub>3</sub> (CH <sub>2</sub> ) <sub>10</sub> CO <sub>2</sub> CH <sub>3</sub>	<b>12a</b> , 93 <b>12b</b> , 4
5	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>11</sub> OH	<b>12</b>	MeOH 63	64	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>10</sub> CO <sub>2</sub> (CH <sub>2</sub> ) <sub>11</sub> CH <sub>3</sub> CH <sub>3</sub> (CH <sub>2</sub> ) <sub>10</sub> CO <sub>2</sub> CH <sub>3</sub>	<b>12a</b> , 86 <b>12b</b> , 7
6	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>11</sub> OH	<b>12</b>	HO(CH <sub>2</sub> ) <sub>2</sub> OH 8	14	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>10</sub> CO <sub>2</sub> (CH <sub>2</sub> ) <sub>11</sub> CH <sub>3</sub>	<b>12a</b> , 90
7	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>9</sub> OH	<b>11</b>	CH <sub>3</sub> CO <sub>2</sub> H 1.1	14	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>8</sub> CO <sub>2</sub> (CH <sub>2</sub> ) <sub>9</sub> CH <sub>3</sub>	<b>11a</b> , 92

<sup>a</sup> Substrate (S): 0.25 mmol; PHPB: 0.5 mmol; H<sub>2</sub>O: 8 mL.

<sup>b</sup> PHPB: 1.0 mmol.

<sup>c</sup> Isolated yield.

**Table 6** Esterification of Aliphatic Primary Alcohols with PHPB in Water<sup>a</sup>

Run	Substrate	S	Time (h)	Product	Yield (%) <sup>b</sup>
1		<b>13</b>	17		<b>13a</b> , 87
2		<b>14</b>	14		<b>14a</b> , 90
3		<b>15</b>	14		<b>15a</b> , 90
4		<b>16</b>	14		<b>16a</b> , 92
5		<b>17</b>	16		<b>17a</b> , 96
6		<b>18</b>	75		<b>19</b> , 82

<sup>a</sup> Substrate (S): 0.25 mmol; PHPB: 0.5 mmol; H<sub>2</sub>O: 8 mL.

<sup>b</sup> Isolated yield.

In contrast with aliphatic alcohols, aromatic ones have been known to be brominated with perbromide easily.<sup>1a,2</sup> Further, benzylic alcohols have been oxidized to give aromatic carbonyl compounds by many oxidative agents.<sup>1a</sup> Therefore, there has been interest in the dimeric esterification of aromatic primary alcohols by PHPB–H<sub>2</sub>O. The following experiments were carried out to examine the dimeric esterification of aromatic alcohols. First, the reaction of benzyl alcohol was carried out under the same reaction conditions. Dimeric ester was not obtained in high yield accompanied by benzaldehyde (**2**) at 2.0 molar

equivalents of PHPB over benzyl alcohol (6%). Even at 4.0 molar equivalents of PHPB over benzyl alcohol, a mixture of **2**, 4-bromo-benzaldehyde (**9**), and benzoic acid was afforded unfortunately. Even in the presence of methanol, benzyl alcohol was recovered unchanged in 74% yield. Benzyl alcohol was not easily converted to both dimeric ester and methylester **2a** in the presence of methanol by PHPB–H<sub>2</sub>O. To investigate the above mentioned bromination and dimeric esterification of aromatic alcohols, the reaction of β-phenylethylalcohol was carried out with PHPB–H<sub>2</sub>O. β-Phenylethylalcohol was brominated

to give a mixture of *o*- and *p*-bromophenylethylalcohols without producing dimeric ester. Therefore, the dimeric esterification of *p*-bromophenylethylalcohol unaffected by further bromination was examined. The reaction of *p*-bromophenylethylalcohol with PHPB–H<sub>2</sub>O afforded dimeric ester in 53% yield. It was suggested that dimeric esterification of aromatic alcohols progressed favorably under the conditions which depressed bromination for the aromatic ring. The polybromination reaction of organic compounds by perbromide has been known to be suppressed in the presence of pyridine.<sup>14</sup> Therefore, the esterification of 2-methyl-2-phenylpropanol was carried out in the presence of 2.0 molar equivalents of pyridine over 2-methyl-2-phenylpropanol. Dimeric ester was obtained in 61% yield, which was beyond our expectation.<sup>15</sup> As mentioned above, Tishchenko-like dimeric esterification of variable aromatic alcohols in contrast with aliphatic alcohols, has turned out to be particularly difficult with PHPB–H<sub>2</sub>O. It is necessary to study further optimal esterification methods for converting aromatic alcohols to dimeric esters in moderate yields.

Although a variety of oxidizing reagents have been shown to convert primary alcohols with methanol into methyl carboxylates by intermolecular esterification and diols into lactones by intramolecular esterification,<sup>16–20</sup> there are few methods for the synthesis of Tishchenko-like dimeric esters of primary alcohols without using organic solvents. Thus, the system PHPB–H<sub>2</sub>O also provides a significant alternative method for obtaining Tishchenko-like dimeric esters of various aliphatic primary alcohols without using organic solvents.<sup>21</sup>

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- (7) The oxidation of 2-ethyl-1,3-hexanediol (**18**) containing both secondary and primary hydroxyl groups, was carried out with 2.0 molar equiv of PHPB over **18** in H<sub>2</sub>O at r.t. for 75 h. Only the secondary 3-hydroxyl group of **18** was selectively oxidized to give hydroxyketone **19** in 82% yield (Table 6, run 6).
- (8) **Typical procedure for the Esterification of Isobutyraldehyde (4) and Dodecanol:**  
To a solution of PHPB (320 mg, 1.00 mmol) in H<sub>2</sub>O (8 mL) were added **4** (36 mg, 0.50 mmol) and dodecanol (93 mg, 0.50 mmol). After stirring for 14 h at r.t., the reaction mixture was treated with 0.5 M aq Na<sub>2</sub>S<sub>2</sub>O<sub>3</sub> and extracted with EtOAc. The organic layer was washed with 0.5 M aq Na<sub>2</sub>S<sub>2</sub>O<sub>3</sub>, successively sat. aq NaCl, and dried over MgSO<sub>4</sub>. After removal of the solvent in vacuo, the residue was purified by column chromatography on silica gel (Wakogel C-200) with CCl<sub>4</sub> and CHCl<sub>3</sub> (3:1 v/v). Ester **4a** (109 mg, 0.42 mmol) was obtained in 84% yield.
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- (21) **Typical Procedure for the Dimeric Esterification of Dodecanol (12):** To a solution of PHPB (160 mg, 0.50 mmol) in H<sub>2</sub>O (8 mL) was added **12** (46 mg, 0.25 mmol).

After stirring for 13 h at r.t., the reaction mixture was treated with 0.5 M aq Na<sub>2</sub>S<sub>2</sub>O<sub>3</sub> and extracted with EtOAc. The organic layer was washed with 0.5 M aq Na<sub>2</sub>S<sub>2</sub>O<sub>3</sub>, successively sat. aq NaCl, and dried over MgSO<sub>4</sub>. After removal of the solvent in vacuo, the residue was purified by column chromatography on silica gel (Wakogel C-200) with CCl<sub>4</sub>. Dimeric ester **12a** (44 mg, 0.12 mmol) was obtained in 95% yield.