Montmorillonite clay catalysis. Part 10.[1] K-10 and KSF-catalysed acylation of alcohols, phenols, thiols and amines: scope and limitation

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Montmorillonite K-10 and KSF are highly efficient catalysts for the acetylation of a variety of alcohols, thiols, phenols and amines with acetic anhydride. Amino groups can be selectively acetylated in the presence of hydroxy groups, while the hydroxy groups can be preferentially acetylated in the presence of thiol groups. No selectivity is observed between primary and secondary hydroxy groups in the presence of K-10 and KSF. The catalysts are found not to be efficient for acetylation of tertiary alcohols. This method is simple and convenient with minimum environmental impact. The catalysts are also effective for the acylation of alcohols, thiols, phenols and amines with acetyl chloride and benzoyl chloride. Cyclic anhydrides such as succinic anhydride, maleic anhydride and phthalic anhydride and *p*-toluene sulfonyl chloride show less reactivity than acetic anhydride and acyl chlorides.

Introduction

Although a variety of procedures use transesterification methodology,[2] the acylation of alcohols and phenols is routinely carried out using acid anhydrides or acyl chlorides in the presence of tertiary amines such as triethylamine and pyridine.[3] 4-(Dimethylamino)pyridine (DMAP) and 4-pyrrolidinopyridine (PPY) are known to catalyse this reaction and to increase the rate of acylation by a factor of 10^4 (ref. 4). Recently, Vedejs and co-workers reported tributylphosphine to be a similar catalyst for the acylation of alcohols.[5] In addition to the above catalysts, protic acids such as toluene-*p*-sulfonic acid[6] and Lewis acids such as zinc chloride,[7] cobalt chloride[8] and scandium trifluoromethanesulfonate[9] are also known to catalyse the acylation of alcohols with acid anhydrides. Nevertheless, there is still a great demand for acid catalysts to generate esters under mild conditions and environmentally friendly processes.

Montmorillonite clays, a class of inexpensive and non-corrosive solid acids, have been used as efficient catalysts for a variety of organic reactions.[10] The reactions catalyzed by montmorillonite clays are usually carried out under mild conditions with high yields and high selectivities and the work-up of these reactions is very simple; only filtration to remove the catalyst and evaporation of the solvent are required. Montmorillonite clays are easily recovered and reused. In a recent publication on the preparation of acylals from aldehydes catalyzed by montmorillonite clays, we found that hydroxy groups were protected as acetates in hydroxy-containing aromatic aldehydes.[11] In a preliminary communication we have shown that montmorillonite K-10 and KSF are efficient catalysts for the acetylation of alcohols, thiols, phenols and amines with acetic anhydride.[12] To explore the generality and scope of the above montmorillonite K-10 and KSF-catalyzed acylation, this paper describes a detailed account of these reactions along with the scope and limitation of the catalysts.

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Results and discussion

It has been shown earlier[12] that alcohols, thiols, phenols and amines are efficiently acetylated with acetic anhydride in the presence of a catalytic quantity of montmorillonite K-10 or KSF in CH_2Cl_2, $CHCl_3$ or CCl_4 at room temperature (rt) or at refluxing temperature (Scheme 1). The molar quantity of acetic

Scheme 1

anhydride is quite crucial to the success of the acetylation; when the molar amount of alcohol, thiol or amine and acetic anhydride are equal, the yield of the acetate or acetamide is moderate and is accompanied by starting material. In the cases of polyhydroxy, hydroxy amine and alcohol compounds it gives a mixture of the fully acetylated and partially acetylated products and unreacted material. The results are compiled in Table 1. Generally K-10 works better than KSF in terms of reaction time, temperature and/or yield (Table 1, entries 1, 5, 12, 15 and 28). Primary (**1**, **2**, **3**, **4**, **6** and **11**) and secondary (**4**, **5** and **6**) alcohols and phenols (**13**–**25**) can be easily acetylated at room temperature or in refluxing CH_2Cl_2 or $CHCl_3$. In some cases the reaction can be carried out under solvent free conditions especially for those with liquid starting materials (Table 1, entries 1, 2, 12, 13, 16 and 19–22). No selectivity between primary and secondary hydroxy groups is observed (Table 1, entries 4 and 6). Different results are obtained for several tertiary alcohols. For example, triphenylmethanol **7** remains unchanged even when the reaction is performed in refluxing CCl_4 for 2 h (Table 1, entry 7). α-Hydrogen-containing tertiary alcohols mainly provide the dehydration products. For example, *tert*-butyl alcohol **8** gives 2-methylpropene **8a** (Table 1, entry 8) in excellent yield (94%). When heated in refluxing CH_2Cl_2 for 2 h, 3β-methyl-5α-cholestan-3α-ol **10** affords 3-methyl-5α-cholest-2-ene **9b** as the exclusive product. However, 3α-acetoxy-3β-methyl-5α-cholestan **10a** can be obtained in 27% net yield based on 27.5%

Table 1 Acetylation of alcohols, thiols, phenols and amines with acetic anhydride catalysed by K-10 and KSF

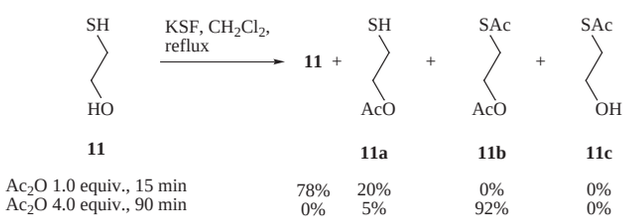
Entry	Substrate	Catalyst-Solvent T(°C)/t(h)	Ratio[a]	Product	Yield[b] (%)	Bp (°C) (Torr) or Mp (°C) Found	Reported
1	Octanol **1**	K-10/none/rt/1	2:1	Octyl acetate **1a**	96	212(760)	98(15)[13]
		KSF/none/rt/4	2:1	Octyl acetate **1a**	96		
2	Benzyl alcohol **2**	KSF/none/rt/1	2:1	Benzyl acetate **2a**	90	230(760)	134(102)[14]
3	Ethylene glycol **3**	KSF/$CHCl_3$/62/2	4:1	Ethane-1,2-diyl diacetate **3a**	76	189(760)	186[14]
4	Glycerol **4**	KSF/$CHCl_3$/62/2	6:1	Propane-1,2,3-triyl triacetate **4a**	95	252(760)	258[15]
5	Cholesterol **5**	K-10/CH_2Cl_2/rt/2	2:1	Cholesteryl acetate **5a**	98	113–114	114–115[14]
		KSF/$CHCl_3$/62/2	2:1	Cholesteryl acetate **5a**	98		
6	Dihydrobetulin **6**	K-10/CH_2Cl_2/40/3	2:1	3β,28-Diacetoxylupane **6a**	94	250–252	256–257[16]
7	Triphenylmethanol **7**	KSF/CCl_4/76/2	2:1	No reaction	—		
8	*tert*-Butyl alcohol **8**	KSF/none/80/0.25	2:1	2-Methylpropene **8a**	94	−7 to 6	−6.6[14]
9	3α-Methyl-5α-cholestan-3β-ol **9**	K-10/CH_2Cl_2/40/2	2:1	3β-Acetoxy-3α-methyl-5α-cholestane **9a**	23	109–110	84–86[17]
				3-Methyl-5α-cholest-2-ene **9b**	49	82.5–83	80–81[17]
10	3β-Methyl-5α-cholestan-3α-ol **10**	K-10/CH_2Cl_2/35/1	2:1	3α-Acetoxy-3β-methyl-5α-cholestane **10a**	27[c]	49–50	79–81[17]
				3-Methyl-5α-cholest-2-ene **9b**	49[c]	82.5–83	80–81[17]
11	2-Mercaptoethanol **11**	KSF/CH_2Cl_2/40/0.25	1:1	2-Mercaptoethyl acetate **11a**	20	170(760)	55(13)[14]
	2-Mercaptoethanol **11**	KSF/CH_2Cl_2/40/1.5	4:1	2-(Acetylthio)ethyl acetate **11b**	92	196(760)	95(15)[14]
12	Benzenethiol **12**	K-10/none/rt/2	2:1	*S*-Phenyl thioacetate **12a**	97	112(13)	222–223[18]
		KSF/none/rt/5	2:1	*S*-Phenyl thioacetate **12a**	92		
13	Phenol **13**	KSF/none/rt/3.5	2:1	Phenyl acetate **13a**	83	194(760)	196[14]
14	α-Naphthol **14**	KSF/$CHCl_3$/62/4	2:1	α-Naphthyl acetate **14a**	87	44–44.5	48–49[14]
15	β-Naphthol **15**	K-10/CH_2Cl_2/rt/2.5	2:1	β-Naphthyl acetate **15a**	98	68–68.5	70[14]
		KSF/CH_2Cl_2/40/2	2:1	β-Naphthyl acetate **15a**	98		
16	3-Nitrophenol **16**	KSF/none/rt/5	2:1	3-Nitrophenyl acetate **16a**	98	53–54	55–56[14]
17	2-Nitrophenol **17**	KSF/$CHCl_3$/62/7	2:1	2-Nitrophenyl acetate **17a**	93	38–39	40–41[14]
18	4-Nitrophenol **18**	KSF/CH_2Cl_2/40/2.5	2:1	4-Nitrophenyl acetate **18a**	98	76–77.5	81–82[14]
19	2-Methylphenol **19**	KSF/none/rt/3.5	2:1	2-Methylphenyl acetate **19a**	90	210(760)	208[14]
20	4-Methoxyphenol **20**	KSF/none/rt/4.5	2:1	4-Methoxyphenyl acetate **20a**	92	30.5–31	32[19]
21	Hydroquinone **21**	KSF/none/rt/2	4:1	Benzene-1,4-diyl diacetate **21a**	98	68–68.5	70[14]
22	Catechol **22**	KSF/none/rt/3	4:1	Benzene-1,2-diyl diacetate **22a**	98	62–63	63.5[14]
23	Resorcinol **23**	KSF/$CHCl_3$/62/3	4:1	Benzene-1,3-diyl diacetate **23a**	78	280(760)	278[14]
24	Benzene-1,3,5-triol **24**	KSF/$CHCl_3$/62/4.5	6:1	Benzene-1,3,5-triyl triacetate **24a**	83	104–105	104[14]
25	2-Aminophenol **25**	KSF/CH_2Cl_2/40/1	2:1	*N*-(2-Hydroxyphenyl)acetamide **25a**	72	202–203	208[14]
26	2-Aminophenol **25**	KSF/CH_2Cl_2/40/3	4:1	*N*-(2-Acetoxyphenyl)acetamide **25b**	70	126–127	129–130[20]
27	Diisopropylamine **26**	KSF/CH_2Cl_2/40/2	4:1	*N*-Diisopropylacetamide **26a**	98	195(760)	94.5(12)[21]
28	2-Nitroaniline **27**	K-10/CH_2Cl_2/40/3.5	2:1	2-Nitroacetanilide **27a**	98	92–93	94[14]
		KSF/CH_2Cl_2/40/3.5	2:1	2-Nitroacetanilide **27a**	87		

[a] Acetic anhydride : substrate (mol : mol). [b] Isolated yield. [c] Net yield, conversion rate of the material is 27.5%

conversion rate of **10** together with the major product **9b** (49% net yield) when heated at 35 °C for 1 h (Table 1, entry 10). The equatorial hydroxy epimer, 3α-methyl-5α-cholestan-3β-ol **9**, gives the corresponding acetate **9a** in better yield (23%) and **9b** (49%) (Table 1, entry 9). It is noteworthy that **9b** is the exclusive dehydration product in both reactions. This is confirmed by $AgNO_3$–silica gel TLC[22] and by ^1H NMR spectroscopy. These results indicate that K-10 and KSF are not efficient catalysts for acetylation of tertiary alcohols. Polyhydroxy compounds were however, transformed into the corresponding polyacetates (Table 1, entries 3, 4, 6 and 21–24).

In the presence of K-10 or KSF, thiols and amines are also converted into the corresponding thioacetates and acetamides (Table 1, entries 11, 12 and 25–28). Acetylation of thiols is slower than for alcohols (Table 1, compare entries 12 and 13). When 2-mercaptoethanol **11** is treated with 1 equivalent of acetic anhydride in the presence of KSF in refluxing CH_2Cl_2 for 15 min, 2-mercaptoethyl acetate **11a** is formed in 20% isolated yield and 78% of **11** is recovered. When four equivalents of acetic anhydride is employed, however, after refluxing in CH_2Cl_2 for 90 min, **11** provides a mixture of **11a** and 2-(acetylthio)ethyl acetate **11b** in isolated yields of 5 and 92% respectively. 2-(Acetylthio)ethanol **11c** is not detected in either reaction (Scheme 2).

Amino groups can be preferentially acetylated in the presence of hydroxy groups (Table 1, entries 25 and 26). Upon treatment with two equivalents of acetic anhydride in the presence of KSF, 2-aminophenol **25** in refluxing CH_2Cl_2 for 1 h gives



Scheme 2

N-(2-hydroxyphenyl)acetamide **25a** in 72% isolated yield and 16% of **25** is recovered. When four equivalents of acetic anhydride is employed, however, after refluxing in CH_2Cl_2 for 3 h, **25** provides a mixture of **25a** and *N*-(2-acetoxyphenyl)-acetamide **25b** in isolated yields of 15 and 70% respectively. 2-Acetoxyphenylamine **25c** is not found in both reactions (Scheme 3).

To extend the scope and the generality of montmorillonite clay-catalyzed acylation, we have also investigated montmorillonite K-10 catalyzed acetylation of alcohols, thiols, phenols and amines with acid chlorides such as acetyl chloride (AcCl), benzoyl chloride (BzCl) and *p*-toluene sulfonyl chloride (TsCl) by using several typical substrates. As shown in Table 2, in the presence of K-10, acetylation of these active hydrogen-containing compounds can be carried out in CH_2Cl_2 at rt in quantitative yields (Table 2, entries 1, 4, 7, 10 and 13). Benzoylation of alcohols, thiols, phenols and amines is also achieved in good to excellent yield (60–97%, Table 2, entries 2, 5, 8, 12

Table 2 K-10-Catalyzed acylation of alcohols, phenols, thiols and amines with acyl chloride

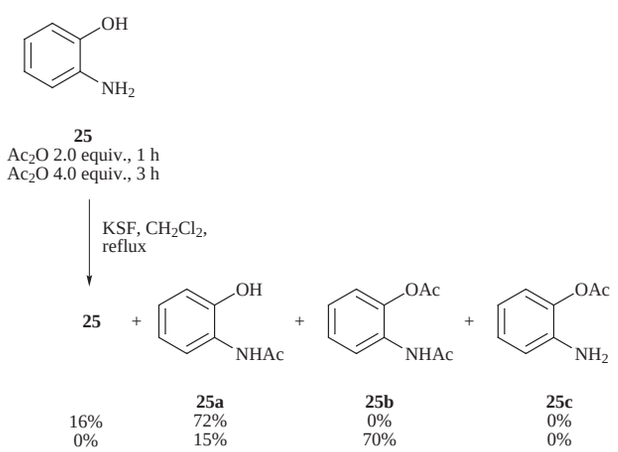
Entry	Substrate		Solvent/ T(°C)/t(h)	Ratio[a]	Product	Yield[b] (%)	Bp (Torr) or Mp (°C) Found	Reported
1	**1**	AcCl	CH_2Cl_2/rt/0.5	1.5 : 1	**1a**	98	212(760)	98(15)[13]
2	**1**	BzCl	CH_2Cl_2/40/8	1.2 : 1	Octyl benzoate **1b**	95	304(760)	180–182(20)[23]
3	**1**	TsCl	CCl_4/76/30	1.2 : 1	Octyl tosylate **1c**	38	175(13)	155–156(2)[24]
4	**5**	AcCl	CH_2Cl_2/rt/1.5	1.5 : 1	**5a**	98	113–114	114–115[14]
5	Cyclo-hexanol **28**	BzCl	CH_2Cl_2/40/6	1.2 : 1	Cyclohexyl benzoate **28a**	60	284(760)	285(760)[25]
6	**5**	TsCl	CCl_4/76/12	1.2 : 1	Dicholesteryl ether **5c**	38	195–196	200–203[26]
					Cholesta-3,5-diene **5d**	27	77–78	79–80[27]
7	**13**	AcCl	CH_2Cl_2/rt/2	1.5 : 1	**13a**	98	194(760)	196[14]
8	**13**	BzCl	CH_2Cl_2/40/0.5	1.2 : 1	Phenyl benzoate **13b**	97	67–68	71[14]
9	**13**	TsCl	CH_2Cl_2/40/2	1.2 : 1	No reaction	—	—	—
10	**12**	AcCl	CH_2Cl_2/rt/6	1.5 : 1	**12a**	98	111–113	90(7–8)[18]
11	**12**	BzCl	CH_2Cl_2/rt/0.7	1.2 : 1	*S*-Phenyl thiobenzoate **12b**	63	54–55	56[28]
12	**12**	TsCl	CCl_4/76/36	1.2 : 1	No reaction	—	—	—
13	**27**	AcCl	CH_2Cl_2/rt/1.5	1.5 : 1	**27a**	98	92–93	94[14]
14	Aniline **29**	BzCl	CH_2Cl_2/rt/0.25	1.2 : 1	Benzanilide **29a**	93	163–165	164–165[29]
15	Aniline **29**	TsCl	CH_2Cl_2/40/1	1.2 : 1	*N*-Phenyltoluene-*p*-sulfonamide **29b**	95	98–100	98–101[30]

[a] Acyl chloride : substrate (mol : mol). [b] Isolated yield.

Table 3 K-10- or KSF-catalyzed acylation of alcohols, thiols, phenols and amines with cyclic anhydrides

Entry	Substrate	Cyclic anhydride	Catalyst/ Solvent/ T(°C)/t(h)	Ratio[a]	Product	Yield[b] (%)	Bp (Torr) or Mp (°C) Found	Reported
1	**1**	Succinic anhydride	K-10/CCl_4/76/6	1.2 : 1	3-(Octyloxycarbonyl)-propionic acid **1d**	70	36–37	36.9–37.2[32]
2		Maleic anhydride	K-10/CCl_4/76/20	0.5 : 1	Monooctyl maleate **1e**	23	30–30.5	32–32.5[33]
					Dioctyl maleate **1f**	71	250(13)	246(10)[34]
3		Phthalic anhydride	K-10/CCl_4/76/12	0.6 : 1	Monooctyl phthalate **1g**	54	22–23	22.5–23.5[35]
					Dioctyl phthalate **1h**	21	380(760)	185(1)[36]
4	**5**	Succinic anhydride	KSF/CCl_4/76/12	1.2 : 1	3-(Cholesteryloxycarbonyl)-propionic acid **5e**	60	175–178	178–180[37]
5	**13**	Succinic anhydride	KSF/CCl_4/76/60	1.2 : 1	Monophenyl succinate **13c**	40	91–93	97–98[38]
					Diphenyl succinate **13d**	16	120–121	120–121[38]
6	**12**	Succinic anhydride	K-10/CCl_4/76/36	1.2 : 1	No reaction	—	—	—
7	**29**	Succinic anhydride	K-10/CCl_4/76/12	1.2 : 1	*N*-(Phenyl)succinamic acid **29c**	92	143–145	144–145[39]
8		Maleic anhydride	K-10/CCl_4/76/12	1 : 1	*N*-(Phenyl)maleamic acid **29d**	73	194–195	201[39]

[a] Cyclic anhydride : substrate (mol : mol). [b] Isolated yield.



Scheme 3

and 14). It should be noted that these reactions proceed much slower in the absence of K-10 catalyst. The tosylation of alcohols, thiols and phenols, however, shows very little tendency under K-10 catalysis. *n*-Octanol **1** gives only 38% of octyl toluene-*p*-sulfonate (tosylate) (Table 2, entry 3), whereas cholesterol **5**, benzenethiol **12** and phenol **13** cannot be tosylated. In the presence of K-10 cholesterol **5** provides, after refluxing in CCl_4 for 12 h, a complex mixture from which dicholesteryl ether **5c** and cholesta-3,5-diene **5d** were isolated and identified (Table 2, entry 6). Previously we demonstrated that in the presence of K-10 disteryl ethers could be obtained in good yields from the corresponding sterols in refluxing CH_2Cl_2.[26] Cholesta-3,5-diene **5d** was a by-product in the arylation of cholesterol catalyzed by K-10.[31] Consequently, the formation of **5c** and **5d** from the present reaction is reasonable. Benzenethiol **12** and phenol **13** remain unchanged with TsCl in refluxing CCl_4 and CH_2Cl_2 respectively (Table 2, entries 12 and 9). The tosylation of aniline **29**, however, results in an excellent yield of *N*-phenyltoluene-*p*-sulfonamide **29b** (95%) (Table 2, entry 15).

Catalysis by montmorillonite K-10 and KSF is also observed with cyclic anhydrides, but the reactions are considerably slower than the Ac_2O experiments. The results of the acylation with cyclic anhydrides are shown in Table 3. A mixture of phenol and succinic anhydride was refluxed in CCl_4 for 60 h to give monophenyl succinate **13c** and diphenyl succinate **13d** (16%) (Table 3, entry 5). Benzenethiol cannot be acylated with succinic anhydride under these conditions. Cholesterol gives 60% succinate **5e** (Table 3, entry 4). However, the acylation of aniline results in an excellent yield of **29c** (92%) (Table 3, entry 7).

Under similar conditions we have also tried performing the acylation with maleic anhydride. Octanol **1** provides monooctyl maleate **1e** (23%) and dioctyl maleate **1f** (71%) (Table 3, entry 2). Phenol **13** and benzenethiol **12** give no reaction with maleic anhydride. Aniline **29** affords 73% of *N*-(phenyl)maleamic acid **29d**. Cholesterol **5** cannot be acylated with maleic anhydride

in refluxing CCl_4 for 12 h, a mixture of dicholesteryl ether **5c** and cholesta-3,5-diene **5d** is obtained instead. The conversion of phthalic anhydride into esters has also been tested. Phthalic anhydride is relatively unreactive towards benzenethiol, aniline or phenol with catalysis by montmorillonite K-10 or KSF. However, reaction of octanol **1** with phthalic anhydride in refluxing CCl_4 for 24 h gave monooctyl phthalate **1g** (54%) and dioctyl phthalate **1h** (21%). Cholesterol **5** reacted with phthalic anhydride to give dicholesteryl ether **5c** and cholesta-3,5-diene **5d**.

Conclusions

In summary, we have demonstrated that montmorillonite K-10 and KSF are good acetylation catalysts for primary and secondary alcohols, phenols, thiols and amines with acetic anhydride but not for tertiary alcohols. Amino groups can be selectively acetylated in the presence of hydroxy groups while the hydroxy groups can be preferentially acetylated in the presence of thiol groups. However, no selectivity is observed between primary and secondary hydroxy groups. The catalysts are also effective for the acylation of alcohols, thiols, phenols and amines with acetyl chloride and benzoyl chloride. Cyclic anhydrides and *p*-toluene sulfonyl chloride show less reactivity than acetic anhydride and acyl chlorides. The present method has the additional advantages of mild conditions, high yield, easy set-up and work-up and non-corrosive inexpensive and environmentally friendly catalysts.

Experimental

Materials and methods

Boiling and melting points are uncorrected. ^{1}H NMR spectra were recorded on a Varian INOVA-500 or on a Bruker AC-80 spectrometer in $CDCl_3$ with tetramethylsilane as internal reference. *J* Values are given in Hz. Montmorillonite K-10 and KSF were purchased from Aldrich and used directly. The products were separated or purified by column chromatography on silica gel.

Typical procedure for acetylation of alcohols with acetic anhydride (Table 1, entry 5)

To a mixture of cholesterol **5** (1.94 g, 5.00 mmol), K-10 (100 mg) and CH_2Cl_2 (10 cm^3) was added acetic anhydride (1.02 g, 10.0 mmol). After being stirred at room temperature for 2 h, the catalyst was removed by filtration and washed with CH_2Cl_2 (10 cm^3). The solvent was evaporated under reduced pressure. The residue was pure enough for general purposes and further purification was achieved by column chromatography on silica gel to give cholesteryl acetate **5a** (2.10 g, 98%).

3-(Octyloxycarbonyl)propionic acid 1d. δ_H(500 MHz) 0.88 (3H, t, *J* 7.0, CH_3), 1.25–1.35 (10H, m, 5 × CH_2), 1.62 (2H, quintet, *J* 7.1, $CO_2CH_2CH_2CH_2$), 2.61–2.70 (4H, m, O_2CCH_2-CH_2CO_2H), 4.09 (2H, t, *J* 7.0, $CO_2CH_2CH_2$) and 9.68 (1H, br s, CO_2H).

Monooctyl phthalate 1g. δ_H(500 MHz) 0.84 (3H, t, *J* 7.0, CH_3), 1.20–1.32 (8H, m, 4 × CH_2), 1.395 (2H, quintet, *J* 7.0, $CO_2CH_2CH_2CH_2CH_2$), 1.74 (2H, quintet, *J* 7.0, CO_2CH_2-CH_2CH_2), 4.33 (2H, t, *J* 6.8, $CO_2CH_2CH_2$), 7.53 (1H, dt, *J* 1.0 and 7.3, Ar-H), 7.57 (1H, dt, *J* 1.0, 7.3, Ar-H), 7.69 (1H, dd, *J* 1.0, 7.3, Ar-H), 7.88 (1H, dd, *J* 1.0, 7.3, Ar-H) and 9.71 (1H, br s, CO_2H).

Dioctyl phthalate 1h. δ_H(500 MHz) 0.88 (6H, t, *J* 7.0, 2 × CH_3), 1.25–1.32 (16H, m, 8 × CH_2), 1.40 (4H, quintet, *J* 7.0, 2 × $CO_2CH_2CH_2CH_2CH_2$), 1.73 (4H, quintet, *J* 7.0, 2 × CO_2-$CH_2CH_2CH_2$), 4.295 (4H, t, *J* 7.0, 2 × $CO_2CH_2CH_2$), 7.51–7.54 (2H, m, Ar-H_2) and 7.70–7.73 (2H, m, Ar-H_2).

Ethane-1,2-diyl diacetate 3a. δ_H(80 MHz) 2.03 (6H, s, 2 × $COCH_3$) and 4.21 (4H, s, 2 × CH_2).

Propane-1,2,3-triyl triacetate 4a. δ_H(80 MHz) 2.05 (3H, s, $COCH_3$), 2.07 (6H, s, 2 × $COCH_3$), 4.00–4.41 (4H, m, 2 × CH_2) and 5.23 (1H, m, CH).

2-Mercaptoethyl acetate 11a. δ_H(80 MHz) 1.47 (1H, t, *J* 8.5, SH), 2.07 (3H, s, CH_3), 2.74 (2H, td, *J* 6.6 and 8.5, $HSCH_2$) and 4.18 (2H, t, *J* 6.6, $CH_2O_2CCH_3$).

2-Acetylthioethyl acetate 11b. δ_H(80 MHz) 2.05 (3H, s, $CH_2O_2CCH_3$), 2.32 (3H, s, CH_2SOCCH_3), 3.10 (2H, t, *J* 6.5, CH_2SOCCH_3) and 4.18 (2H, t, *J* 6.5, $CH_2O_2CCH_3$).

***N*-(2-Hydroxyphenyl)acetamide 25a.** δ_H(80 MHz, [$^2H_6$]DMSO) 2.08 (3H, s, CH_3), 6.86 (3H, m, Ar-H_3), 7.65 (1H, d, *J* 7.4, Ar-H), 9.27 (1H, br s, NH) and 9.67 (1H, s, OH).

***N*-(2-Acetoxyphenyl)acetamide 25b.** δ_H(80 MHz) 2.14 (3H, s, $NCOCH_3$), 2.34 (3H, s, O_2CCH_3), 7.14 (4H, m, Ar-H_4) and 8.05 (1H, br s, NH).

Treatment of *tert*-butyl alcohol 8 with acetic anhydride in the presence of KSF (Table 1, entry 8)

A mixture of *tert*-butyl alcohol **8** (2.24 g, 30.0 mmol), acetic anhydride (6.12 g, 60.0 mmol) and KSF (600 mg) was heated on an oil bath with good stirring at 80 °C for 15 min. The product 2-methylpropene **8a** was introduced through a vertical water condenser and collected (1.60 g, 94%) with a cold trap (−20 °C).

Preparation of 3α-methyl-5α-cholestan-3β-ol 9 and 3β-methyl-5α-cholestan-3α-ol 10

The alcohols **9** and **10** were prepared from 5α-cholestan-3-one (217.8 mg, 0.564 mmol) and methylmagnesium iodide as described previously.[17,40] Separation by silica gel column chromatography gave 3α-methyl-5α-cholestan-3β-ol **9** (87.4 mg, 39%), mp 147–149 °C (lit.,[17] 146 °C; lit.,[40] 147–148 °C) and 3β-methyl-5α-cholestan-3α-ol **10** (127.4 mg, 57%), mp 126–128 °C (lit.,[17] 125 °C; lit.,[40] 126–127 °C).

Acetylation of 3α-methyl-5α-cholestan-3β-ol 9 (Table 1, entry 9)

A mixture of **9** (22.5 mg, 0.0560 mmol), acetic anhydride (11.4 mg, 0.112 mmol), K-10 (10 mg) and CH_2Cl_2 (2 cm^3) was heated at refluxing temperature for 2 h. The catalyst was removed by filtration and the solvent was evaporated under reduced pressure. The residue was separated by column chromatography on $AgNO_3$/silica gel[22] to give 3-methyl-5α-cholest-2-ene **9b** (10.6 mg, 49%), mp 82–83 °C (lit.,[17] 80–81 °C; lit.,[40] 82–83 °C); δ_H(80 MHz) 0.66 (3H, s, 18-CH_3), 0.71 (3H, s, 19-CH_3), 0.86 (6H, d, *J* 6.1, 26,27-di-CH_3), 0.91 (3H, d, *J* 6.4, 21-CH_3), 1.73 (3H, s, C_3-CH_3) and 5.29 (1H, br s, 4-H) and 3β-acetoxy-3α-methyl-5α-cholestan **9a** (5.7 mg, 23%); δ_H(80 MHz) 0.65 (3H, s, 18-CH_3), 0.82 (3H, s, 19-CH_3), 0.86 (6H, d, *J* 6.3, 26, 27-di-CH_3), 0.90 (3H, d, *J* 5.7, 21-CH_3), 1.55 (3H, s, 3α-CH_3) and 2.01 (3H, s, O_2CCH_3).

Acetylation of 3β-methyl-5α-cholestan-3α-ol 10 (Table 1, entry 10)

A mixture of **10** (106.0 mg, 0.263 mmol), acetic anhydride (53.9 mg, 0.528 mmol), K-10 (20 mg) and CH_2Cl_2 (2 cm^3) was heated at 35 °C for 1 h. The same work-up as described above was applied to provide **9b** (13.8 mg, net yield 49%), 3α-acetoxy-3β-methyl-5α-cholestan **10a** (8.6 mg, net yield 27%), mp 49–50 °C (lit.,[17] 79–81 °C); δ_H(80 MHz) 0.64 (3H, s, 18-CH_3), 0.76 (3H, s, 19-CH_3), 0.86 (6H, d, *J* 6.0, 26,27-di-CH_3), 0.89 (3H, d, *J* 6.4, 21-CH_3), 1.55 (3H, s, 3β-CH_3) and 1.99 (3H, s, O_2CCH_3) and recovered **10** (76.8 mg, conversion 27.5%).

Acknowledgements

This project was supported by NSFC (2957039), Natural Science Foundation of Hebei Province (297065) and the Science and Technology Commission of Hebei Province.

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Paper 8/02051E
Received 13*th March* 1998
Accepted 16*th April* 1998