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The Reaction between Acyl Halides and Alcohols: Alkyl Halide vs. Ester Formation

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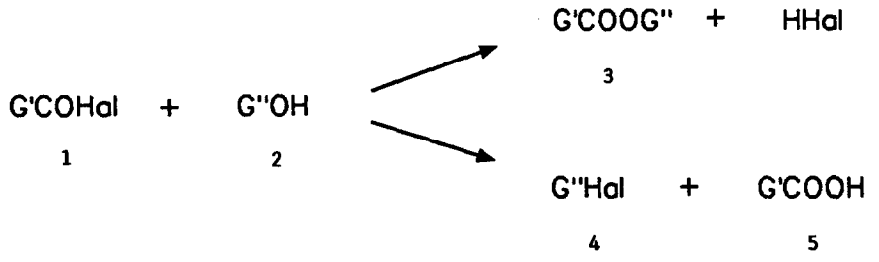
Abstract: In the reaction between an acyl halide and an alcohol the thermodynamically favoured products are the free carboxylic acid and the alkyl halide. The initial reaction is, generally, the formation of an ester and HHal. When the alcohol is very prone to yield an alkyl cation upon protonation by HHal, formed H_2O exhibited a superior reactivity and competed successfully with the alcohol for the acyl halide making, therefore, ester formation practically confined to a triggering role. But, in those cases where the cation is less easily formed, ester formation was favoured and, consequently, became the necessary elementary step towards alkyl halide formation. This final product, on the other hand, might be extremely slow to form in an S_N2 reaction between the protonated ester function and the halide ion. In these instances, therefore, as well as in the cases when a basic solvent competes for the proton of HHal, the ester is the final product. A notable exception of the situation above outlined, is given by α-hydroxy-α-phenylbenzeneacetic acid (2y), which appears to undergo direct chlorine-hydroxyl interchange through a quaternary intermediate (E), in the end collapsing to α-chloro-α-phenylbenzeneacetic acid (4y). Different systems were compared using CH_2Cl_2 as a solvent under strictly similar conditions. Some 28 different substrates were tested for reaction with AcCl (1a), whereas the action of eight acyl halides (1) against (*RS*)-α-methylbenzenemethanol (2n) and α-phenylbenzenemethanol (2p), as well as the effect of five different solvents on the reaction between two alcohols (2p and 2-methyl-2-propanol, 2c) with 1a, were observed.

INTRODUCTION

Carboxylic acid halides (1) are well known to react with alcohols (2) to give esters (3) in excellent yields[1] and, on this general assumption,

many mechanistic works were performed,[2] but, on the other hand, in a number of cases the alternate formation of an alkyl halide 4 and a carboxylic acid 5 was reported (Equation 1).[3] The production of tertiary



(1)

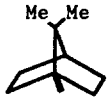
alkyl chlorides from oxalyl chloride and tertiary alcohols was observed as early as 1916:[4] the substrates on which the reaction took place, are somehow suggestive of an S_N1 mechanism, but no detailed study was done. Actually, this behaviour forms the basis of a method of preparation of some alkyl halides (4) from the corresponding alcohols (2) and acetyl chloride (1a) or bromide (1b).[5] As if this reaction needed to be somehow forced or its actual stoichiometry were different from the 1:1 above envisaged, excess 1 was almost constantly employed. Such mechanistic situation was overshadowed by the discovery that 1a indeed reacts with α-phenylbenzenemethyl acetate (3p) to yield acetic anhydride (6) and chlorodiphenylmethane (4p)[6] and, in another instance, with α,α-diphenylbenzenemethyl acetate (3t) affording chlorotriphenylmethane (4t).[7] Thus, whereas the mechanistic picture of the reaction is unclear; also, its scope and the most convenient way to carry it out are to be clarified.

RESULTS AND DISCUSSION

Reactions of Alcohols with Acetyl Halides

The results of our extensive study of the reaction of 1a with alcohols (2) in CH_2Cl_2 are collected in Table 1. α-Phenylbenzenemethanol (2p) afforded the corresponding chloride (4p, 98%) when treated with one equivalent of acetyl chloride (1a) for 1 h at rt. When the same reaction, conveniently run at 0°C, was monitored during the first hour, an initial prevalent formation of the ester 3p was observed, but the concentration of the chloride 4p took the lead very soon at 50% consumption of the initial substrate. The reaction of the acetate 3p with HCl was found to be of comparable rate, whereas its reaction with 1a was extremely slow even at

Table I. Reactions between G˜OH (2) and AcCl (1a)[a]

Alcohol (2)	G˜	Products (%)		Unreacted 2 (%)	Separated Yield (Product, %)
		G˜Cl (4)	G˜OAc (3)		
2a[b]	n-C_6H_{13}	0	100	0	3a, 93
2b[b]	Cyclohexyl	0	100	0	3b, 93
2c	Me_3C	69	22	9	4c, 81[c]
2d[b]	1-Methylcyclohexyl	90	10	0	4d, 82
2e[d]	1-Adamantyl	52	48	0	4e, 75[e]
2f[d]		0	65	35	3f, 93[f]
2g	(*E*)-1-Methyl-2-butenyl	100	0	0	4g, 92[g]
2h[b]	(*E*)-2-Hexenyl	0	100	0	3h, 91
2i[b]	(*Z*)-2-Hexenyl	0	100	0	3i, 88
2j[b]	1-Ethenylbutyl	0	100	0	3j, 87
2k	2-Cyclohexenyl	100	0	0	4k, 78[g]
2l[b]	$PhCH_2$	0	100	0	3l, 97
2m	(*E*)-3-Phenyl-2-propenyl	47	53	0	4m, 72[h]
2n	Ph(Me)CH	45	55	0	4n, 93[i]
2o	$Ph(Me)_2C$	100	0	0	4o, 82
2p[b,j]	Ph_2CH	98	2	0	4p, 91
2q	4-MeOPh(Ph)CH	100	0	0	4q, 79
2r	4-O_2NPh(Ph)CH	10	90	0	3r, 82
2s	Ph_2MeC	57[k]	0	0	$Ph_2C{=}CH_2$, 88
2t[d,l]	Ph_3C	100	0	0	4t, 83
2u[d,l]	9-Fluorenyl	15	67	18	4u, 84[m]

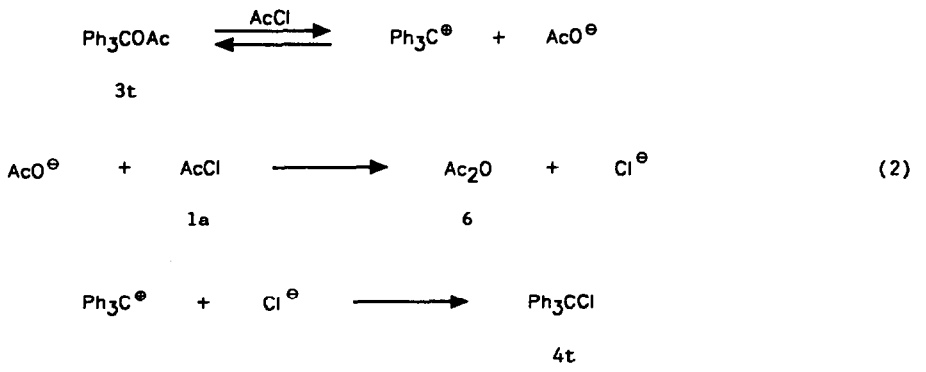
(Continued)

Table 1 (Continued)

2v[d,l]	9-Methyl-9-fluorenyl	90[n]	0	0	4v, 90[n]
2w[d]	9-Phenyl-9-fluorenyl	100	0	0	4w, 81
2x[b]	PhCH(COOH)	0	100	0	3x, 89
2y[d,l]	Ph_2C(COOH)	88	12	0	4y, 80
2z	Ph_2C(COOMe)	0	20	80	4z, 61[o]
2α[p]	9-(COOH)-9-fluorenyl	31	44	25	4α, 66[p]
2β[d,l]	9-(COOMe)-9-fluorenyl	0	12	88	3β, 85[q]

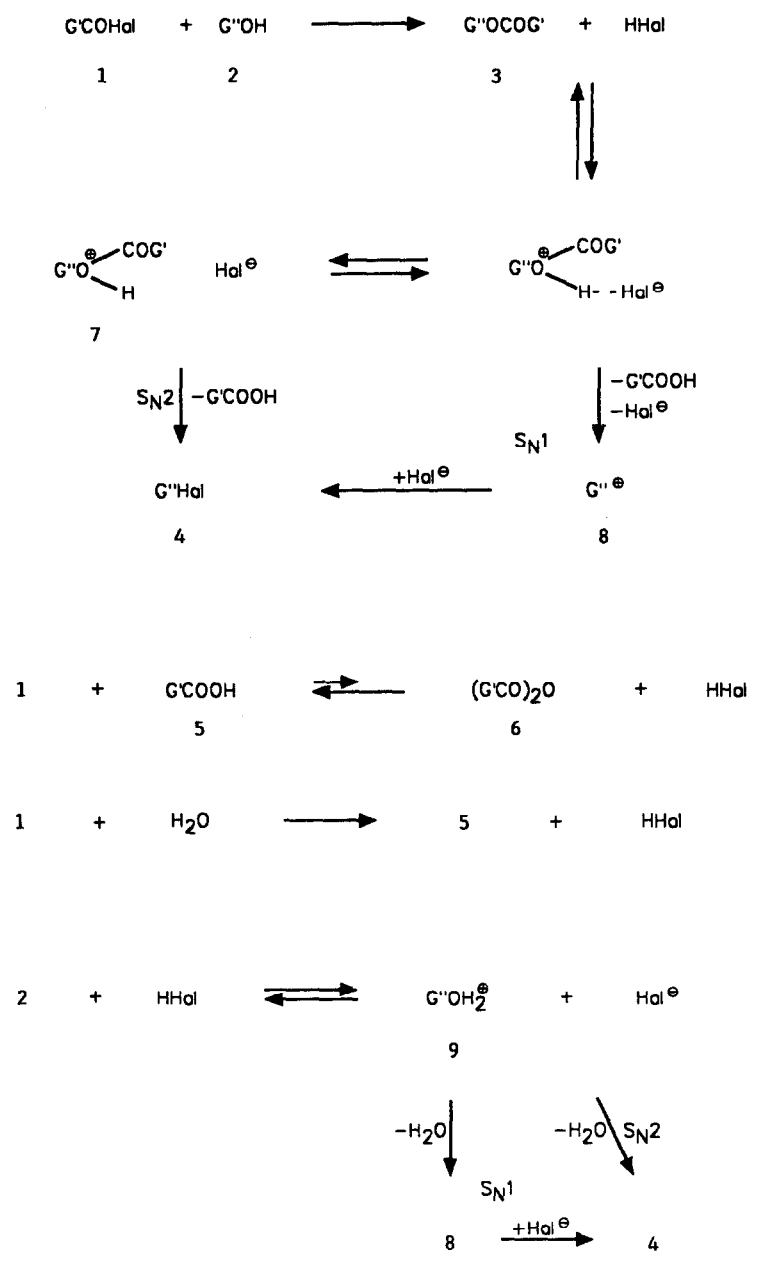
[a] Reaction conditions are described in the experimental part, unless specified otherwise; compositions of the mixtures are recorded at 1 h rt and, for slower reactions, at longer times. [b] No change in composition was observed after 24 h. [c] At 2 h: 77, 23, 0; at 24 h: 84, 16, 0. [d] The mixture initially non-homogeneous gave a clear solution within 1 h. [e] After saturation with HCl, at rt during 3 d; composition: 86, 14, 0. [f] At 24 h: 0, 96, 4. [g] Work up of the mixture with CH_2N_2 (see experimental part). [h] At 72 h: 82, 18, 0. [i] At 24 h rt: 62, 38, 0; after saturation with HCl (24 h rt): 96, 4, 0. [j] In the experiment carried out at 0°C the following results were recorded: at 1 min: 1, 4, 95; at 15 min: 26, 22, 52; at 25 min: 67, 24, 9; at 45 min: 80, 18, 2. [k] Also 43% 1,1-diphenylethane. [l] Double amount CH_2Cl_2 was employed. [m] At 2 h: 35, 65, 0; at 24 h: 50, 50, 0; after saturation with HCl, at rt during 24 h, composition: 96, 4, 0. [n] Also 10% 9-methylene-9H-fluorene. [o] At 4 h: 12, 44, 44; at 24 h: 71, 25, 4. [p] slurry; at 24 h: 65, 31, 4; after saturation with HCl, at rt during 24 h: 87, 13, 0. [q] At 24 h: 0, 89, 11; at 48 h: 0, 95, 5.

reflux temperature (6% 4p after 4 h). Analogous behaviour was observed for 1,1-dimethylethyl acetate (3c), but hexyl acetate (3a) and benzenemethyl acetate (3l) did not react at all with 1a.[8] These facts ruled out any significant contribution of this reaction to the formation of 4p from 1a and 2p. As a consequence, the apparently fast reaction (3 h, reflux, 90% yield) between 3p and 1a reported in the literature[6] was probably due to the presence of free HCl in the reaction mixture, whereas the rapid formation of chlorotriphenylmethane (4t) in the reaction between α,α-diphenylbenzenemethyl acetate (3t) and 1a[7] might be rationalized as outlined in Equation 2.



Brown[9] has established that 2p reacts instantly and practically completely (93%) with one equivalent of HCl in dry CH_2Cl_2 at 0°C to yield the corresponding chloride 4p and H_2O (Table 1); moreover, the great rapidity of the reaction of AcCl with H_2O is of common experience.[10] The overall picture leads to identify a mechanism, where the initial formation of the ester 3p produces HCl which, well before reaching possible saturation, in turn reacts very rapidly with the alcohol 2p generating the halide 4p and H_2O. From this point onward H_2O, by its instant reaction with 1a, will be by far the main supplier of HCl to the system, the latter taking also care of any *slowly* formed 3p. Equilibration of an equimolecular mixture of AcOH (5a) and the chloride 4p led after 1 h to practically the same composition of the reaction mixture which it was arrived at by starting from the same concentrations of 2p and 1a under identical conditions. As a definitive evidence, we observed that in a competitive experiment, where 2p and 3p were present in equimolecular concentrations in their reaction with HCl, the alcohol was indeed the only substrate entering the reaction, the key factor being its higher basicity. The actual mechanism and the other alternatives are summarized in Scheme 1.

When α-phenylbenzenemethanol (2p) was the limiting reagent striving for equimolecular concentrations of acetyl chloride (1a) and bromide (1b), bromination prevailed over chlorination by a 9 to 1 ratio, no acetate 3p being observed. The more reactive[11] 1b liberated Br^- which eventually ended up in bromodiphenylmethane (4pb). The key reaction is anyhow the protonation of the alcohol 2p and/or the acetate 3p by formed HHal; any H_2O formed would preferentially react with 1b to produce more HBr, which, inter alia, is known to be more acidic than HCl. The known production[12] of HCl and Ac_2O (6) from 1a and formed AcOH caused eventually HCl to react with 4pb, inducing its slow transformation into the chloride 4p. In



Scheme 1. Overall Reaction Mechanisms for the System Alcohol-Acyl Halide.

another experiment, a defective concentration of **1a** was put to react with equimolecular amounts of benzenemethanol (**21**) and α-phenylbenzenemethanol (**2p**): the alcohol **21** was very prompt to react with **1a** to yield benzenemethyl acetate (**31**) and HCl which, on the other hand, gave **4p** from **2p** in a very prone reaction. A much lesser amount of HCl was intercepted in a slower S_N2 reaction by surviving **21** yielding chloromethylbenzene (**41**): a separate experiment allowed to rule out formation of the latter directly from **31** and HCl, in line with the behaviour shown by the esters of primary aliphatic alcohols, like hexyl acetate (**3a**). Benzenemethanol (**21**) underwent extensive bromination upon reaction with **1b** in CH_2Cl_2: the difference of reactivity of the two acyl halides is rationalized in terms of the higher mobility of the Br^-.

The observed behaviour of the esters **31** and **3p** with HCl allows to infer about the mechanism of the substitution reaction. In fact, their basicity under these experimental conditions must be essentially the same and therefore identical should be the extent of their protonation to **7** (Scheme 1). Cation **7** may break down to the carbocation **8** if this is stable enough or, in alternative, the acid **5** is an excellent nucleofuge; **8** will eventually combine with Hal^- to yield the halide **4**. Whenever the S_N1 mechanism does not work, there is a possibility of an S_N2 reaction, which should occur between a *free* halide ion and the protonated species **7**. If the esterification reaction is the trigger in a system initially perfectly devoided of free HCl, insofar it produces this species, it is definitively the alcohol, in its protonated form (**9**), the by far more reactive substrate.

The reactions with Ph_2CHX (X=OH, Cl, OAc) all appeared quite reversible; this fact, combined with the other observations, lead to the conclusion that the product-system alkyl halide (**4**) - carboxylic acid (**5**) is by far the most stable one. Conversely, it appears that when the end product was the ester **3** the reaction was under kinetic control. Incidentally, the role of acetic anhydride (**6**)[12] was to be considered minimal in these reactions,[13] both because of the tiny concentrations of the acid **5a** simultaneously present with **1a** and the overriding velocity of other reactions; by and large, equilibration of equimolecular concentrations of AcCl and AcOH yielded only ca. 6% **6** in a very rapid reaction: this conforms with previously reported data[14] and is in agreement with the observation that the unfavourable equilibrium needs the presence of a base to be driven to the right.[15]

Influence of the Solvent

Consistently with expectation, changing the solvent from CH_2Cl_2 to the

basic Et_2O caused a dramatic effect on product distribution. In fact, after 1 h the system **1a-2p** had evolved to a 2:1 ratio of the halide **4p** vs. the acetate **3p**. The solvent effect was even more pronounced when 2-methyl-2-propanol (**2c**) was the substrate under the same conditions: similar results had been previously observed for the system **1a-2c** when the reaction was carried out without solvent and in the presence of pyridine[16] or N,N-dimethylbenzeneamine.[17] The correlation of the outcome of the reaction with solvent basicity was further supported by the results obtained for the same systems in CH_3CN, EtOAc and DMF: whereas the overall rate of consumption of the initial alcohols was essentially the same, the conversion into esters or chlorides varied as shown in Table 2.

Table 2. Reaction of α-Phenylbenzenemethanol (2p) and 2-Methyl-2-propanol (2c) with AcCl (1a) in Different Solvents at Room Temperature

G˜OH[a]	Solvent[b]	Time (h)	Products (%)		
			G˜Cl	G˜OAc	Unreacted G˜OH
2p	CH_2Cl_2	1	99	1	0
		12	98	2	0
2p	CH_3CN	1	98	2	0
2p	CH_3COOCH_3	1	71	29	0
2p	Et_2O	1	64	35	1
		12	83	17	0
2p	DMF	1	23	77	0
2c	CH_2Cl_2	1	69	22	9
2c	CH_3CN	1	62	28	10
2c	CH_3COOCH_3	1	34	39	27
2c	Et_2O	1	10	63	27
2c	DMF[c]	1	4	79	17

[a] 5.0 mmol; AcCl (1a): 5.6 mmol. [b] 0.6 mL. [c] Containing 20% CH_3CN.

Influence of the Structure of the Alcohol

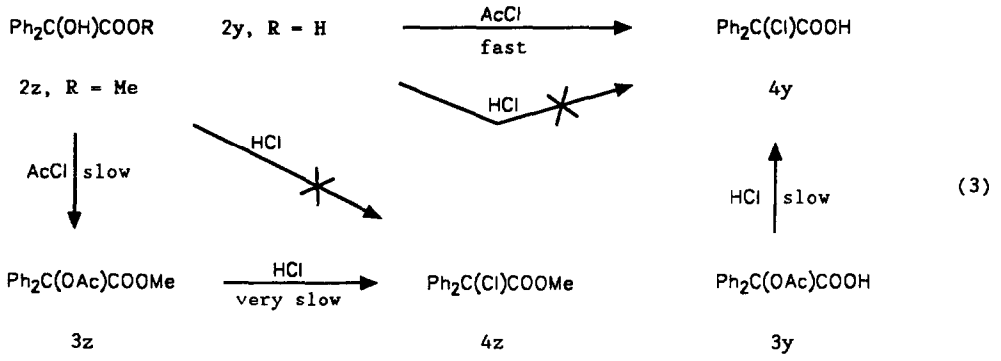
1-Methylcyclohexanol (**2d**), (*RS*)-(*E*)-3-penten-2-ol (**2g**), (*RS*)-2-cyclohexen-1-ol (**2k**), 2-phenyl-2-propanol (**2o**), α-phenylbenzenemethanol (**2p**), (*RS*)-4-methoxy-α-phenylbenzenemethanol (**2q**), 1,1-diphenylethanol (**2s**), α,α-diphenylbenzenemethanol (**2t**), 9-methyl-9H-fluoren-9-ol (**2v**), 9-phenyl-9H-fluoren-9-ol (**2w**) and α-hydroxy-α-phenylbenzeneacetic (benzilic) acid (**2y**) all gave 90-100% conversion to the corresponding chlorides when treated with AcCl, the balance being given by the corresponding acetates. With the exception of compound **2y**, these substrates are expected to easily undergo S_N1 reaction upon protonation of the starting alcohols or intermediate acetates.

Hexanol (**2a**), cyclohexanol (**2b**), (*E*)- and (*Z*)-2-hexen-1-ol (**2h** and **2i**), (*RS*)-1-hexen-3-ol (**2j**), benzenemethanol (**2l**), (*RS*)-4-nitro-α-phenylbenzenemethanol (**2r**), bicyclo[2.2.1]heptan-7,7-dimethyl-1-ol (1-apocanphanol, **2f**), (*RS*)-α-hydroxybenzeneacetic (mandelic) acid (**2x**) and methyl 9-hydroxy-9H-fluorene-9-carboxylate (**2β**) all gave only the acetates when treated with **1a** in the usual way. Even for very long reaction times there was no evidence for the evolution of these systems to the corresponding chlorides. In all these cases the carbocations, essential intermediates[9] for the S_N1 reaction, were not formed and the chloride ion did not appear to be reactive enough[18] to carry out a nucleophilic S_N2 attack on any oxonium ion possibly present. In all the instances where either the end product of the reaction between **1a** and an alcohol **2** was the corresponding acetate **3**, or the acetates were formed first and thus became the essential intermediates on the way to chlorides **4**, we observed that primary alcohols were consumed much faster than the secondary and very sluggishly tertiary substrates.

We also found systems for which an even partition occurred between the two reaction outcomes. 2-Methyl-2-propanol (**2c**), (*RS*)-1-phenylethanol (**2n**), (*E*)-3-phenyl-2-propen-1-ol (cinnamyl alcohol, **2m**), tricyclo-[3.3.1.1^{3,7}]decan-1-ol (1-adamantanol, **2e**), 9H-fluoren-9-ol (**2u**), 9-hydroxy-9H-fluorene-9-carboxylic acid (**2α**) and methyl α-hydroxy-α-phenylbenzeneacetate (benzilate, **2z**) reacted with AcCl partly giving the acetates (**3**) and partly the chlorides (**4**). Generally, longer reaction times led to higher concentrations of **4**. More extensive chlorination was also achieved by adding gaseous HCl to the mixtures. In other terms, the substitution reactions (on the acetates) are possible under these circumstances, but ionization is slower for both the alcohol (**2**) and the acetate (**3**) and/or less favourable, thus allowing time to build up larger concentrations of the esters, which become the actual preferential intermediates. Except for these systems, the O-acetylation appeared to be

the essential triggering step for the chlorination reaction, but then the very fast reaction between the alcohol (2) and HCl set in for ionizable substrates leading to the chloride (4) and H_2O, which, in turn, produces more HCl by its rapid reaction with 1a. This mechanism was dramatically confirmed by reacting an equimolecular mixture of the alcohol 2n and the corresponding acetate 3n with one equivalent of HCl in CH_2Cl_2: 2n was transformed completely into the chloride (4n) without 3n undergoing any change. Since a protonated acetate group appears to be a better leaving group than a H_2O molecule from a protonated alcohol, the difference in basicity of the two systems must be the key factor.

It was interesting to observe that methyl α-hydroxy-α-phenyl-benzeneacetate (2z) was quicker to yield the acetate 3z than the chloride 4z, just because the chlorination reaction slowly goes through the intermediate 3z, which is the activated form (better leaving group) of 2z (Equation 3). Substrate 2z was indeed completely unreactive towards excess

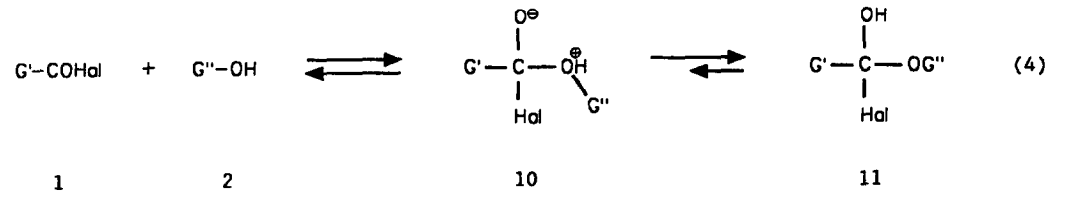


HCl even in AcOH. This behaviour is in sharp contrast with the much faster reaction of the corresponding free acid 2y with 1a to yield directly the chloride 4y:[5i] this matter has received attention in a recent report,[19] but deserves a closer look. First, we shall notice that, notwithstanding the reaction under our conditions was originally heterogeneous, being the acid 2y not very soluble, its rate was high and the occurrence of the ester 3y was about 10% at the time (less than 1 h) of the complete consumption of 2y. When the anhydrous[19] acetate ester 3y was submitted to a large excess of HCl in CH_2Cl_2, it was transformed into 4y at a rate incomparably lower than that of the reaction between 2y and 1a: 26% after 1 h at 0°C, 72% after 24 h at rt. The ester 3y reacted with 1a very

sluggishly to the chloride **4y**; moreover, it should be emphasized that **2y** did not react at all with HCl even in AcOH for prolonged reaction times. The analogous fluorene derivatives **2α** and **2β** reacted with AcCl producing comparable amounts of chloride **4α** and ester **3α**, and ester **3β** only, respectively.[20] This was the reflection of the increased difficulty of delocalizing a positive charge passing from a diphenylmethyl to a fluorenyl cation, in strict analogy with the observed behaviour of **2p** and **2u**.[21] (*RS*)-α-Hydroxybenzeneacetic acid (**2x**) underwent only acetylation upon reaction with **1a**:[22] this fact may be ascribed to the insufficient stabilization of a naked or incipient carbocation derived from this substrate. In other terms, one may say that acetylation of the hydroxy group bears no sufficient activation for **2β** towards carbon cationization after protonation. In this contest, we may easily rationalize why 9H-fluoren-9-ol (**2u**) goes prevalently to the acetate **3u** in a relatively fast reaction, but both its 9-methyl (**2v**) and 9-phenyl (**2w**) derivatives are quickly transformed only into the chlorides **4v** and **4w**.

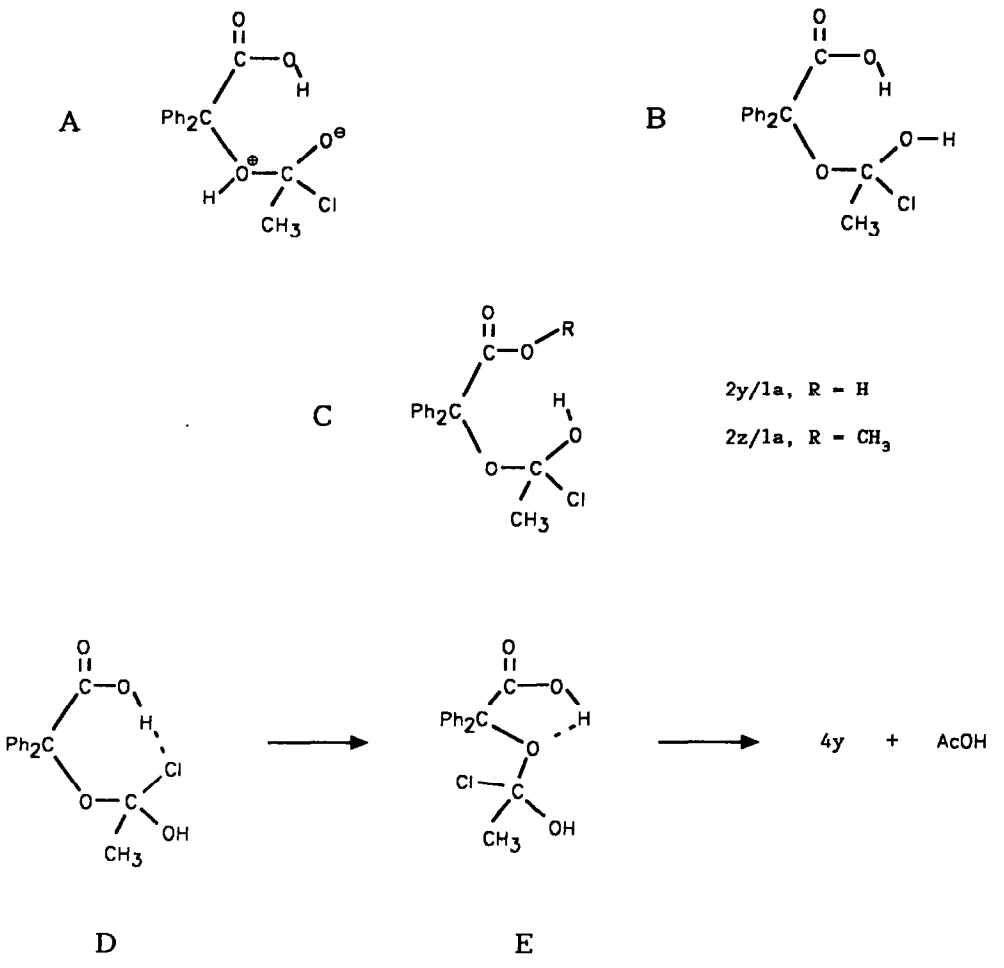
The observations on **2y** ruled out both the mechanism of the preliminary formation of the acetate followed by prompt reaction with HCl and that of the continuous cyclic production of H_2O from the alcohol and HCl from **1a**. Of course, there is no chance for an S_N2 reaction. It seems reasonable, also, that cationic intermediates might not be easily on reach for **2y** and **2z**, due to the presence respectively of a carboxyl or carbomethoxyl group on the central carbon atom. Such cationic species were recently postulated and observed,[23] but the present experimental conditions are very far from the drastic ones required for their production. The anchimeric assistance[24] by the neighbouring oxygen might be invoked in presence of a dissociated carboxyl group, but it is harder to envisage it from an ester group; furthermore, in this instance the next step would be an unlikely S_N2 attack by Cl^- (Scheme 1). The surprising sharp difference between the free acid **2y** and its methyl ester **2z** in their reactions with AcCl may only be reconciled with a special role of a transient intermediate, which is not the acetate **3y** in the case of **2y**. This intermediate is only available in efficacious concentrations from the reaction of **2y** with **1a**, but, on the other hand, is of very hard reach from the interaction of **3y** or **3z** with HCl; also, this intermediate is absent or proceeds to a different fate in the reaction between **2z** and **1a**. Interestingly, both systems **2y** and **2z** showed excellent capability of holding any free HCl formed insofar as they produced, although at widely different rates, high conversion into the respective chlorides **4y** and **4z**. The ability by **2y** of preserving the active intermediate must be somehow related to the H-bonding properties of a free carboxylic group.

Reaction between acid halides **1** and alcohols **2** may proceed through a number of intermediates **10** and **11**, before yielding an ester (Equation 4).[25] The need for solvation of the initial intermediate **10** was assessed experimentally in previous works.[26] The likely intermediates for the



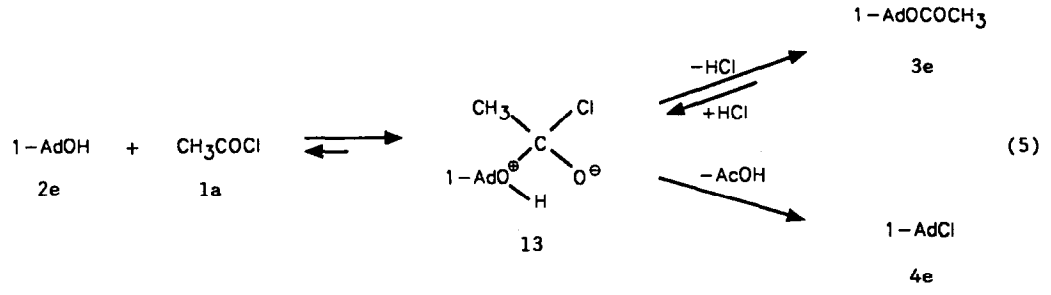
observed behaviour of **3y** and **3z** are either of the structural type **10** or **11**. They are peculiarly stable and/or reactive owing to the stabilizing presence of the COOH or COOMe group. The carboxyl group favours an instant reaction, also; the carbomethoxyl group only favours the retention of HCl in an eventually reactive form. The behaviour observed for **2y** may be then rationalized in terms of an oxygen to halogen 1,3-shift of the α-carboxydiphenylmethyl moiety with expulsion of AcOH: Briegleb-Stuart molecular models evidence a very close proximity of the chlorine atom with the diphenylmethyl α-carbon (Scheme 2). **D** cannot have the same conformation which is active for the slower reaction of the methyl ester **2z**; some other adduct may also be active to a lesser extent in giving the rearrangement-cleavage reaction. A similar situation was previously observed for the reactions of MeOH with α-acyloxy-α-phenylbenzeneacetic acids and their methyl esters,[19] where the free acids showed a marked reactivity at the benzylic center, which underwent methanolysis; the esters, when reactive, on the contrary underwent deacylation. The rationale for the reaction between **2y** and **1a** amounts to the hypothesis of a S_Ni[27] reaction proceeding with the nucleophile entering from the same side of the leaving group.

When we carried out the reaction between AcCl and the two polycyclic bridgehead alcohols **2f** and **2e**, we observed that the former was slowly consumed to yield only the acetate **3f**: this behaviour was in keeping both with the unability of the bridgehead substituent to undergo S_N2 reactions[28] and with the fact that the S_N1 mechanism was also inhibited by the impossibility to produce a flat cation intermediate.[29a] Our observation ruled out, also, any frontal substitution.[29] The bulkiness of the environment about the hydroxyl group caused a steric hindrance to ester formation. On the other hand,compound **2e**, which is known to undergo



Scheme 2. Likely Conformations of the Adducts between α-Hydroxy-α-phenylbenzeneacetic Acid (2y) or its Methyl Ester (2z) and AcCl (1a).

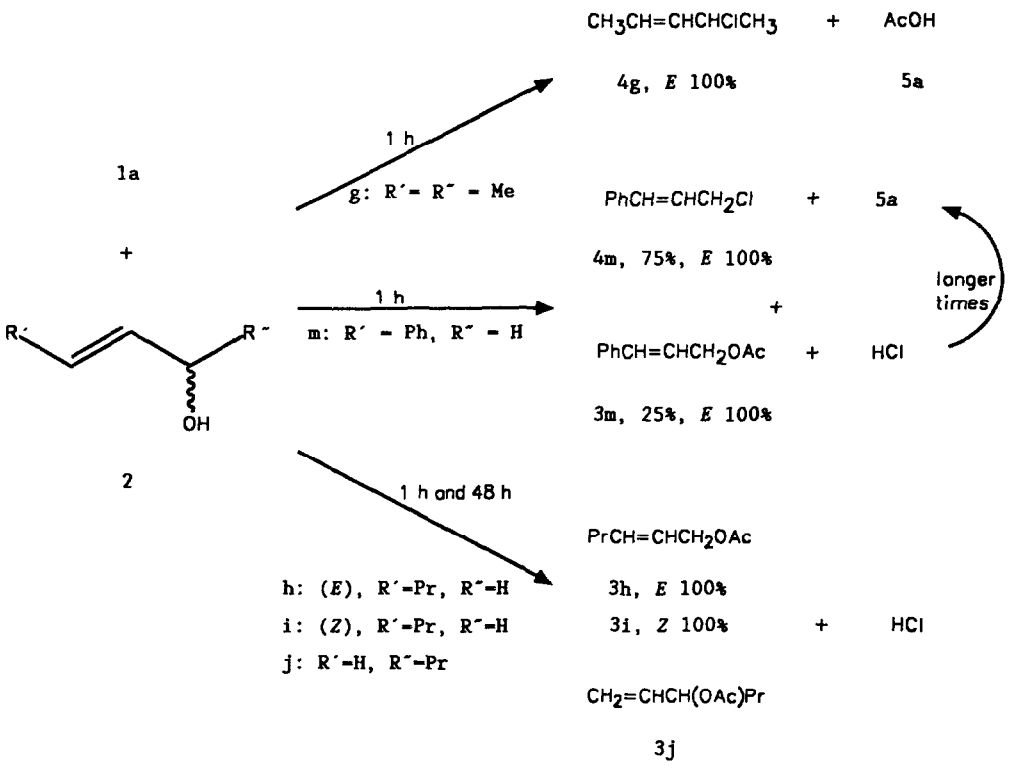
a slow cationization,[30] reacted with AcCl, via the quaternary intermediate 13 (Equation 5), giving an approximately equimolecular mixture of the chloride 4e and the acetate 3e (Equation 5). The kinetically favoured reaction was the loss of HCl to yield the ester 3e; only for longer reaction times the thermodynamic control took over producing more chloride 4e. Eventual saturation of the reaction mixture with HCl completed slowly the conversion to 4e. The fact that some tertiary substrates reacted



rather promptly was due to the de facto automatic enhancement of the rate because liberated HCl from the esterification *instantly* reacted with the alcohol **2** generating the alkyl halide **4** and H_2O and the latter, in turn, produced more HCl by reaction with **1a**, thus largely circumventing the esterification reaction.

Mechanistic Insights

When (*RS*)-(*E*)-3-penten-2-ol (**2g**) reacted with AcCl, we observed the production of only the (*E*)-isomer of the corresponding chloride **4g** by ^1H NMR on the intact reaction mixture (Scheme 3). When this mixture was quenched with CH_2N_2 and distilled (at ca. 100°C) the isolated chloro olefin **4g** did isomerize to yield the thermodynamic composition (*E*/*Z* 85:15)[31] of the two configurational isomers. Since we observed that (*RS*)-1-hexen-3-ol (**2j**) as well as both the (*E*)- and (*Z*)-2-hexen-1-ol (**2h** and **2i**) produced under the same conditions only the corresponding acetate esters **3j**, **3h** and **3i**, respectively, even after prolonged treatment, we may conclude that **2g** is the only one to undergo an S_N1 reaction. The symmetric all trans structure of the intermediate carbocation **14**, as envisaged earlier,[32] did not allow to detect a possible underlying allylic rearrangement. Incidentally, no (*Z*)-isomerization was observed: interconversion all-(*E*)/(*E*)-(*Z*) being comparatively slow,[33] it is mandatory to conclude that the cation $C_5H_9^+$ was formed only from the transoid rotamer. That this was the case for an S_N1 reaction was evidenced by the reaction of (*RS*)-1-deuteriocyclohex-2-en-1-ol (**15**) with **1a**, which yielded the allylic rearrangement 1:1[34] mixture of (*RS*)-3-chloro--3-deuteriocyclohexene (**16**) and (*RS*)-3-chloro-1-deuteriocyclohexene (**17**) since the very inception of the reaction (Equation 6).[35] The rationale for the divergent behaviour of these very similar systems is to be found in the crucial hyperconjugative stabilization offered to the intermediate allyl cation by alkyl groups. Confirmation of this mechanistic picture was



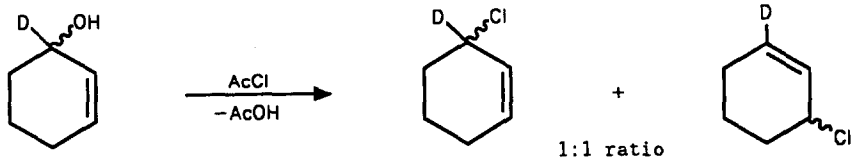
Scheme 3

obtained by the reaction of (*E*)-3-phenyl-2-propen-1-ol (2m) with AcCl which gave a mixture of the corresponding chloride (4m, 100% *E*) and the acetate (3m); the latter eventually slowly changed to the former, indicating that the intermediacy of the ester 3m in the chlorination reaction was partially involved. The phenyl group appeared to provide

14

enough stabilization for cationization, although not with the same efficiency of an alkyl group for each end of the allyl system. The full conservation of the *(E)-configuration, especially for the reaction*

products of 2g, is rationalized as the result of the totally predominant form of the intermediate cation 14. It is noteworthy that the esters 3h, 3i and 3j did not undergo acid catalyzed S_N2 substitution by Cl^-, analogously to benzenemethyl acetate (31).



15 16 17 (6)

Influence of the Nature of the Acyl Halides

Table 3 collects the results of the reaction of alcohols 2n and 2p with a number of different acyl halides (1a-h) under identical conditions. Compound 2n yielded after 1 h more propanoate 3nc than acetate 3n; with this alcohol the corresponding esters are not so easily cationized and eventually transformed into the chlorides and thus they may accumulate. The less bulky ester 3n showed a higher reactivity than 3nc; when 2p was the substrate, the conversions into the chloride 4p were essentially the same with both 1a and 1c as the reactants. This was the result of the high stability and ease of formation of the carbocation from 2p. On the other hand, trimethylacetyl (pivaloyl) chloride (1d) reacted essentially at the same speed of 1a with 2n and the ester was indeed the preferred intermediate to the chloride: reaction of 2n with 1d was a little slower, but the ester 3nd broke down faster to the cation because of the acceleration caused by steric compression. Alcohol 2p was of course less prone to react with 1d than with 1a and 1c and the reaction of 1d itself with formed water appeared to be slower. This resulted in a much depressed rate of consumption of 2p and a grossly changed chloride to ester ratio. On the way to equilibration (24 h) the strong steric acceleration, imposed on the protonated ester 3p, make itself strongly felt resulting in a practically complete conversion to the chloride 4p, whereas the same reaction of protonated 3n was still much behind. The strongly electrophilic trichloroacetyl chloride (1e) reacted very promptly[36] with both alcohols 2n and 2p. The equilibrium was reached within one hour, as it was established by equilibration of equimolecular concentrations of CCl_3COOH (5e) and 4p under identical conditions. Oddly, this ester 3pe

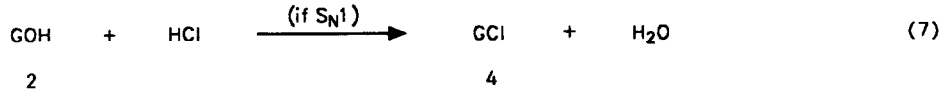
Table 3. Reaction of α-Methylbenzenemethanol (2n) and α-Phenylbenzenemethanol (2p) with Acyl Halides (1)

G'COHal (1)	Reaction time (h)	Ph(Me)CHOH (2n) Composition of the reaction mixture (%)			Ph_2CHOH (2p) Composition of the reaction mixture (%)		
		2n	G'Hal (4n)	G'OCOG' (3)	2p	G'Hal (4n)	G'OCOG' (3)
AcCl (1a)	1	0	47	3n, 53	0	98	3p, 2
	24	0	62	38	0	98	2
AcBr (1b)	1	0	100[a]	3n, 0	0	100[b]	3p, 0
EtCOCl (1c)	1	0	41	3nc, 59	0	98	3pc, 2
	24	0	49	51	0	98	2
Me_3CCOCl (1d)	1	5	50	3nd, 45	30	46	3pd, 24
	24	0	64	36	0	97	3
CCl_3COCl (1e)	1	0	63	3ne, 37	0	88	3pe, 12
	24	0	72	28	0	88	12
PhCOCl (1f)	1	100	0	3nf, 0	100	0	3pf, 0
	24	74	11	15	82	10	8
4-NO_2PhCOCl (1g)	1	97	0	3ng, 3	100[c]	0[c]	3pg, 0[c]
	24	20[c]	50[c]	30[c]	45[c]	31[c]	24[c]
4-MeOPhCOCl (1h)	1	52	17	3nh, 31	72	24	3ph, 4
	24	0[c]	74[c]	26[c]	0[c]	100[c]	0[c]

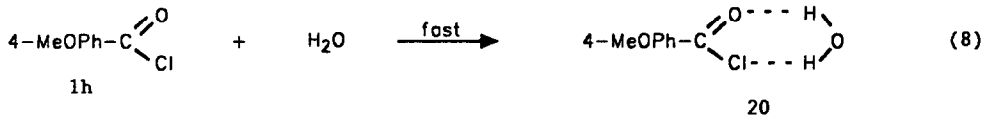
[a] Compound 4nb. [b] Compound 4pb. [c] Heterogeneous reaction mixture.

should provide a better leaving group, but for some reason the C-O bond appears to be more stable, a fact reflected in the chloride 4p/ester 3pe ratio at equilibrium. Alcohol 2n reacted with 1e to yield prevalently the chloride 4n: the overall rate was slower than the corresponding reaction of 2p, but the formation of 4n was more abundant than when the acyl chlorides 1a, c and d were used. This is due to the more pronounced cationization favoured by a better leaving group.

Benzoyl chloride (1f) was found completely unreactive toward 2n and 2p after 1 h; the reaction proceeded at ca. 20% conversion after 24 h, yielding comparable amounts of the corresponding chlorides 4n and 4p and esters 3nf and 3pf. This result leads to the conclusion that the HCl-H_2O-1 cycle, which is working for 1a so efficiently to exclude any important overall contribution of the esterification reaction, is somehow hampered here. Independent experiments confirmed the higher propensity of acyl chlorides to react with alcohols than with H_2O: MeOH, H_2O and 1a, in equimolecular concentration, reacted completely after 3 min at 0°C in THF to yield AcOMe and AcOH (5a) in the 4:1 ratio; in a similar experiment with benzenemethanol (2l), benzenemethyl acetate (3l) prevaled over 5a with a 3:2 ratio. The relatively slow reaction of 4-methylbenzoyl chloride (2i) with equivalent amounts of benzenemethanol (2l) and H_2O resulted in a 63% conversion of the substrate to the corresponding acid 5i (23%) and the benzenemethyl ester 3li (40%), after 24 h at rt and 85% conversion, 33% 5i and 52% 3li, after 48 h. Therefore, H_2O appears invalidated in some manner to explicate the expected reactivity. In the light of the observed higher reactivity of some alcohols than H_2O with the acyl chlorides 1a and i, we may now conclude that the hydrolytic route of 1 to alkyl chlorides 4, here documented in some instances, is to be ascribed to a decrease of the alcolysis of 1 due to steric hindrance. Moreover, HCl is clearly acting as a catalyst for the esterification itself, an event rarely observed in acyl chlorides solvolyses.[37] A p-nitro substituent (1g) improved somewhat the overall conversions, notwithstanding the heterogeneity of the mixture: the ester/chloride ratios[38] were indicative of an analogous mechanism. 4-Methoxybenzoyl chloride (1h) gave much faster reactions than any other aroyl chloride tested both with 2n and 2p. The overall reaction with 2n was more prompt and gave a larger concentration of the ester (3nh) than with 2p after 1 h. This was taken as the immediate evidence for a rate determining step of the ester formation, being the hydrolysis of the aroyl halide slower and the reaction of formed HCl with the alcohols somehow rather slowed down. The alcohol order of many reactions between acyl and aroyl chlorides has been found to be much higher than 1, or, in other terms, the rate of the reaction in aprotic media was found very sensitive to alcohol availability above stoichiometric. This was taken as an indication of the need of solvation of the reactive partners in the transition state.[39] Excess alcohol seems even more dramatically necessary for the realization of the S_N1 mechanism for this reaction.[40] In view of our competitive results we feel that the fastest process of 4-methoxybenzoyl chloride (1h) with both 2n and 2p is due to a sequence of reactions, where the step outlined in Equation 7, inherently fast, is



slowed down by the unavailability of HCl, which appears tied up for the most part by some of the 4-methoxybenxoyl derivatives present in solution. Due to increased electron donating resonance contribution by the *p*-MeO group, direct reaction of **1h** with monomeric H_2O and alcohol is also slowed down. Moreover, H_2O is highly suitable for association of the chloride (Equation 8) being so withdrawn from the medium and becoming the efficient



catalyst for the reaction of alcohol with the halide, instead of acting also as a substrate. Obviously, alcohol activity is also lowered by less strong, but equally acting, associations with 4-methoxy species. The association **1h** - HCl provides another, possibly important, way of enhancing reactivity for **1h**, when the MeO protonated tautomer is formed. This complex scenario rationalized the *faster* reaction of **1h** with *more prevalent* formation of halides.

An overview of our experiments shows that the esterification rates of the different **1** exhibit an overall agreement with the present knowledge of this reaction, except for a few special cases, confirming the rate order α-haloalkanoyl > alkanoyl >> aryl.[41]

CONCLUSIONS

This study shows the variegate mechanisms of the deoxychlorination reaction brought about by acyl halides and the results to be expected upon variation of substrates and reaction conditions. Its usefulness is to be found in the possibility that now opens up to select the instances where the reaction would give the best results in the preparation of a given product and the reaction conditions best suited for the aimed goal.

EXPERIMENTAL

General Methods

Acyl halides were carefully purified by distillation or recrystallization prior to use. Dichloromethane was freshly distilled from CaH_2 after washing with 5% aqueous $NaHCO_3$ followed by treatment with anhyd $CaCl_2$. Diethyl ether was distilled from sodium benzophenone ketyl prior to use. All other commercially available reagents and solvents were reagent grade (Aldrich Italia, Milano) and were used without further purification unless otherwise specified. Alcohols, halides and esters which were not commercially available were prepared with conventional methods (see below). All reactions were carried out in oven-dried glassware under an atmosphere of argon. Alcohol free dry CH_2N_2 in Et_2O was obtained according to a described procedure,[42] followed by treatment with solid KOH. The course of all the reactions described was monitored by GC and GC-MS, previous quenching of the reaction mixture with CH_2N_2, and/or by ^1H NMR after dilution of the reaction mixture as such with a suitable deuterated solvent. Melting points were determined in open ended capillary tubes and are uncorrected. Boiling points refer to the center cut of small distillations and are uncorrected. Elemental analyses were obtained for all isolated compounds and were satisfactory. GC analyses were carried out with a Carlo Erba HRGC gas chromatograph using a 0.25 mm i.d. x 30 m Supelcowax^{TM} 10 and a 0.32 mm x 30 m SPB^{TM} 10 fused silica capillary columns (Supelchem, Milano, Italy). IR spectra were recorded on a Jasco infrared spectrophotometer model DS-702G using the KBr technique; the peak intensity is designated s (strong), m (medium), or w (weak). ^1H and ^{13}C NMR spectra were recorded on a Bruker AC-F spectrometer at 200 and 50 MHz, respectively, in $CDCl_3$ unless otherwise specified. Proton chemical shifts are reported in ppm on the δ scale relative to TMS as an internal reference (0.00). Carbon chemical shifts are reported in ppm relative to the center line of the $CHCl_3$ triplet (77.0). Coupling constants are reported in Hz. The following abbreviations are used: qu (quintet) and sym (symmetrical). Some ^1H NMR multiplets are characterized by the term app (apparent): this refers only to their appearance and may be an oversimplification. MS spectra in the EI positive ion mode, were obtained with a Finnigan 1020 mass spectrometer operating at 70 eV; the five most intense peaks with bracketed relative intensities and the parent ion are reported.

7,7-Dimethylbicyclo[2.2.1]heptan-1-ol (1-Apocamphanol, 2f). This compound was prepared from (*RS*)-10-camphorsulfonic acid by transformation

into the corresponding acid chloride and oxidation to (*RS*)-ketopinic acid,[43a] subsequent reduction to apocamphanic acid,[43b] and final oxidation to **2f**.[43c] The crude alcohol was purified by sublimation at room pressure: colourless needles, mp 162°C (sealed tube); IR 3290s (br), 2930s, 2850w, 1462w, 1449w, 1382w, 1311s, 1289w, 1268m, 1207m, 1171w, 1141s, 1113w, 1060s, 1008w, 999w, 958w, 941w, 911w, 889w, 835w, 660w (br) cm^{-1}; ^1H NMR δ 0.95 (6 H, s, CH_3), 1.30 (2 H, sym app m, C^2-H), 1.45 (1 H, s, OH), 1.48-1.97 (7 H, m, C^2-H + C^3-H + C^4-H); ^{13}C NMR δ 18.24, 27.48, 34.34, 42.03, 45.46, 82.60; MS *m/z* 70 (100), 125 (80), 97 (73), 41 (61), 55 (60), 140 (M^+, 26).

(*RS*)-4-Methoxy-α-phenylbenzenemethanol (2q) and (*RS*)-4-Nitro-α-phenylbenzenemethanol (2r). Compounds **2q** and **2r** were prepared by reduction of the corresponding ketones (100 mmol) with $NaBH_4$ (80 mmol) in dioxane-H_2O (5:1 v/v, 100 mL) and EtOH (300 mL), respectively, during 24 h at rt. After this time, the reaction mixtures were concentrated to a small volume, diluted with Et_2O (300 mL), washed with 1 M H_2SO_4 (2 x 150 mL) and H_2O (1 x 150 mL), dried over Na_2SO_4 and the solvent distilled off. Upon addition of ligroine to the oily residues, crystalline products were obtained. **2q**:[44] yellowish crystals (79% yield), mp 63°C; IR 3360 (br), 2925m, 2810m, 1610m, 1587w, 1509m, 1492m, 1442m, 1390w, 1340w, 1302w, 1250s, 1173s, 1109m, 1030s, 1015s, 1005m, 917w, 859w, 838m, 807s, 777w, 723s, 692m, 650w, 620w cm^{-1}; ^1H NMR δ 2.40 (1 H, br s, OH), 3.76 (3 H, s, CH_3O), 5.76 (1 H, s, PhCH), 6.84 (2 H, sym app m, MeOPh-H), 7.17-7.40 (7 H, m, Ph-H + MeOPh-H); ^{13}C NMR δ 55.20, 75.70, 113.81, 126.35, 127.35, 127.86, 128.36, 136.15, 143.99, 158.95; MS *m/z* 109 (100), 105 (61), 214 (M^+, 59), 135 (58), 77 (54). **2r**:[44] white powder (73% yield), mp 72°C; IR 3400s (br), 3075w, 1592m, 1501s, 1448m, 1337s, 1207w, 1180m, 1100m, 1078m, 1042m, 1020m, 1008m, 858w, 823w, 806m, 757s, 738s, 703s, 689m, 611w cm^{-1}; ^1H NMR δ 2.44 (1 H, br s, OH), 5.91 (1 H, s, PhCH), 7.27-7.43 (5 H, m, Ph-H), 7.57 (2 H, sym app m, O_2NPh-H), 8.18 (2 H, sym app m, O_2NPh-H); ^{13}C NMR δ 75.53, 123.67, 126.70, 127.05, 128.41, 128.95, 142.70, 147.19, 150.70; MS *m/z* 105 (100), 79 (67), 77 (63), 107 (43), 229 (M^+, 33). When reduction of 4-methoxybenzophenone was attempted using EtOH as the solvent, the sole formation of (*RS*)-1-(ethoxyphenylmethyl)-4-methoxybenzene[45a] was observed: yellowish oil (85% yield), bp 120°C/29 Pa;[45] IR (film) 2978m, 1610s, 1583w, 1511s, 1492m, 1450m, 1396w, 1301m, 1247s, 1172s, 1108s, 1090s, 1070s, 1033s, 901w, 861w, 847w, 802m, 782m, 737m, 723m, 709s, 628w cm^{-1}; ^1H NMR δ 1.25 (3 H, t, *J* = 7.0 Hz, $\underline{CH_3}CH_2$), 3.50 (2 H, q, *J* = 7.0 Hz, $CH_3\underline{CH_2}$), 3.76 (3 H, s, CH_3O), 5.32 (1 H, s, PhCH), 6.85 (2 H, sym app m, MeOPh-H), 7.16-7.39 (7 H, m, Ph-H + MeOPh-H); ^{13}C NMR δ 15.33, 55.18, 64.35, 82.98, 113.69, 126.79, 127.18, 128.21, 128.28,

134.72, 142.75, 158.83; MS *m/z* 197 (100), 165 (97), 152 (94), 242 (M^+, 64), 105 (55).

9-Methyl-9H-fluoren-9-ol (2v) and 9-Phenyl-9H-fluoren-9-ol (2w). Compounds 2v and 2w were prepared essentially following a described procedure.[46] 2v:[47] yellowish crystals (91% yield), mp 169°C/hexane-Et_2O; IR 3260s (br), 3010m, 2940m, 2900m, 1608w, 1587w, 1448s, 1395m (br), 1364m, 1295m, 1231w, 1208m, 1153w, 1118m, 1090s, 1049m, 1023m, 935m, 832w, 765s, 727s, 670m (br), 587m cm^{-1}; ^1H NMR δ 1.65 (3 H, s, CH_3), 2.11 (1 H, s, OH), 7.26 (2 H, td, *J* = 7.4 and 1.5 Hz, Fl-H), 7.32 (2 H, td, *J* = 7.4 and 1.6 Hz, Fl-H), 7.47 (2 H, m, Fl-H), 7.57 (2 H, m, Fl-H); ^{13}C NMR δ 25.98, 79.48, 119.93, 123.22, 127.97, 128.80, 138.68, 149.77; MS *m/z* 181 (100), 196 (M^+, 65), 152 (64), 76 (54), 153 (44). 2w:[46] white crystals (75% yield), mp 90°C/ligroine; IR 3390s (br), 3035w, 3000w, 1598w, 1487w, 1446s, 1340w, 1286w, 1182m, 1165m, 1101w, 1038m, 1027m, 915m, 888w, 767m, 750s, 729s, 697s, 640m, 590w cm^{-1}; ^1H NMR δ 2.60 (1 H, br s, OH), 7.15-7.43 (11 H, m, Ar-H), 7.68 (2 H, ddd, *J* = 7.3, 1.4 and 0.7 Hz, Ar-H); ^{13}C NMR δ 83.60, 120.07, 124.78, 125.39, 127.20, 128.20, 128.44, 129.07, 139.59, 143.19, 150.48; MS *m/z* 181 (100), 258 (M^+, 89), 152 (45), 257 (34), 241 (21).

Methyl 9-Hydroxy-9H-fluorene-9-carboxylate (2β). Compound 2β was prepared according to the procedure previously described[19] for the synthesis of methyl α-hydroxy-α-phenylbenzeneacetate (2z): brownish solid (77% yield), mp 160°C/EtOH-H_2O;[48] IR 3450m, 3310m (br), 3010w, 1728s, 1711s, 1470w, 1444m, 1429m, 1395w, 1261m, 1237m, 1218m, 1193s, 1111s, 1070s, 991w, 942w, 800w, 769m, 750s, 743s, 729m, 680w, 618w cm^{-1}; ^1H NMR δ 3.61 (3 H, s, CH_3O), 4.26 (1 H, br s, OH), 7.25-7.47 (6 H, m, Fl-H), 7.67 (2 H, ddd, *J* = 7.4, 1.9 and 0.8 Hz, Fl-H); ^{13}C NMR δ 53.51, 82.34, 120.34, 123.53, 128.15, 129.74, 140.89, 144.93, 174.99; MS *m/z* 181 (100), 152 (57), 153 (31), 182 (27), 151 (17), 240 (M^+, 17).

(*RS*)-1-*d*-2-Cyclohexen-1-ol (15). Compound 15 was prepared following a described procedure,[49c] but the reaction mixture was cautiously quenched with an aqueous solution of the disodium salt of EDTA (0.32 M), which produced a more tractable suspension. The organic phase was separated and three Et_2O extracts of the aqueous phase were combined with it; after washing with a K_2CO_3 saturated aqueous solution, H_2O and drying over Na_2SO_4, the solvent was evaporated and the residue fractionally distilled. Compound 15[34,49] was obtained as a colourless liquid (95% yield): bp 64°C/2133 Pa; IR (film) 3290s (br), 2995m, 2905s, 2835m, 2810m, 2120w, 1647w, 1447w, 1433m, 1385m, 1322w, 1251w, 1221w, 1168m, 1087s, 1069s, 1008m, 963w, 932m, 891w, 868w, 850w, 714s, 660m, 553w cm^{-1}; ^1H NMR δ 1.42-2.14 (6 H, m, CH_2), 3.08 (1 H, br s, OH), 5.72 (1 H, dt, *J* = 10.1 and

1.5 Hz, $=C^2H$), 5.81 (1 H, dt, J = 10.1 and 3.0 Hz, $=C^3H$); ^{13}C NMR δ 18.85, 24.78, 31.51, 64.60 (t, J = 21.9 Hz), 129.82, 129.86; MS *m/z* 71 (100), 83 (42), 99 (M^+, 37), 98 (30), 43 (28). We confirmed that, if acid was used in the work up of the final reaction mixture, 1,3-scrambling of the isotopic label occurred.[34]

General Procedure for the Reaction between an Alcohol (2) and an Acyl Halide (1)

The freshly distilled acyl halide (1, 56 mmol) was added dropwise to a well stirred mixture (solution or suspension) of the alcohol (2, 50 mmol) in anhyd CH_2Cl_2 (6.0 mL) at 0°C under inert atmosphere. The mixture was stirred during 1h after the completion of the addition, while the temperature is allowed to reach ca. 20°C. The reactions leading mainly to the alkyl halides (4) were found to proceed, after an initial induction time, with a rapid evolution of heat: they, therefore, needed a careful control of the temperature and rate of addition. At the end of the allotted time, ^1H NMR and/or GC-MS analyses gave the composition of the reaction mixture as well as the indication for the procedure to be used for the isolation of the reaction products. If the mixture contained the ester (3) prevalently and one wanted to obtain this product, which is invariably rather stable to hydrolysis, H_2O was added and the organic layer was separated, dried over Na_2SO_4 and 3 conveniently purified by distillation or crystallization. Whenever the mixture contained the alkyl halide (4) in sharp prevalence, if this is stable to hydrolysis, the work up was as the one above described; whereas, in the cases when it is H_2O sensitive, the reaction mixture was quenched with CH_2N_2 in Et_2O and the reaction product purified by conventional methods. In intermediate instances, being the halides 4 usually the more valuable compounds, the reaction was driven to this outcome by bubbling gaseous HHal at room temperature into the reaction mixture and, then, applying a suitable work up for the isolation.

An extensive experimentation was carried out in order to observe the effect of the acid halide on the reaction outcome using benzenemethanol (2l), (*RS*)-1-phenylethanol (2n) and α-phenylbenzenemethanol (2p). The reactions were performed exactly under the conditions described above, but the reaction mixture was analyzed as such and the isolation of products was forgone. Table III collects the results concerning the systems 1-2n and 1-2p; 2l and AcBr (1b) gave the acetate 3lb (27%) and the bromide 4lb (73%) at 1 h, which changed respectively to 19% and 81% at 24 h.

1-Methylcyclohexyl Acetate (3d). Compound 3d[50] was prepared according to a described procedure[50a] and obtained (80% yield) as a colourless

liquid: bp 119°C/17329 Pa; IR (film) 2905s, 2835s, 1735s, 1448s, 1367s, 1282m, 1263s, 1232s (br), 1154s, 1106m, 1041m, 1015s, 961m, 941w, 915w, 866w, 807w, 735w, 606w cm^{-1}; ^1H NMR δ 1.12-1.65 (10 H, m, CH_2), 1.47 (3 H, s, CH_3), 2.00 (3 H, s, CH_3CO); ^{13}C NMR δ 22.03, 22.36, 25.32, 25.34, 36.55, 81.64, 170.40; MS *m/z* 43 (100), 81 (81), 96 (67), 55 (50), 71 (44).

1-Chloro-1-methylcyclohexane (4d). Compound 4d[51] was obtained (82% yield) as a colourless liquid: bp 147°C; IR (film) 2910s, 2840s, 1443s, 1376m, 1249m, 1142s, 1088w, 960m, 856w, 770m, 739w, 657w, 565m, 542m cm^{-1}; ^1H NMR δ 1.07-2.16 (10 H, m, CH_2), 1.60 (3 H, s, CH_3); ^{13}C NMR δ 22.62, 25.19, 33.50, 41.56, 72.38; MS *m/z* 81 (100), 55 (70), 97 (65), 96 (57), 41 (39), 132 (M^+, 0.3), 134 (M^+, 0.1).

Tricyclo[3.3.1.1^{3,7}]dec-1-yl (1-Adamantyl) Acetate (3e). Compound 3e[52] was prepared following a described procedure[52c] and obtained as a colourless liquid (89% yield, bp 126°C/3333 Pa) which crystallized on cooling: mp 31°C; IR (film, melted) 2880s, 2830s, 1731s, 1453m, 1364s, 1352s, 1312w, 1239s, 1184w, 1120w, 1100m, 1055s, 1012m, 966m, 948w, 930w, 861m, 811w, 728w, 672w, 665w, 601w cm^{-1}; ^1H NMR δ 1.66 (6 H, app t, C^4H_2 + C^6H_2 + $C^{10}H_2$), 1.96 (3 H, s, CH_3CO), 2.07-2.21 (9 H, m, C^3H + C^5H + C^7H + C^2H_2 + C^8H_2 + C^9H_2); ^{13}C NMR δ 22.58, 30.67, 30.96, 36.08, 41.16, 80.09, 170.10; MS *m/z* 134 (100), 92 (92), 95 (70), 93 (60), 43 (56), 194 (M^+, 3).

7,7-Dimethylbicyclo[2.2.1]hept-1-yl (1-Apocanphanyl) Acetate (3f). The previously unknown 3f was obtained as a colourless liquid (93% yield, bp 105°C/2666 Pa) which solidified on cooling: mp 33°C; IR 2960s, 2910s, 2855s, 1732s, 1460m, 1448w, 1362s, 1304w, 1269m, 1239s, 1158w, 1129m, 1107m, 1045m (br), 997w, 953w, 911w, 791w, 694w, 601w, 555w cm^{-1}; ^1H NMR δ 0.99 (6 H, s, CH_3), 1.36 (2 H, ddd, *J* = 11.6, 9.8 and 3.8 Hz, C^2H + C^6H), 1.57 (1 H, app q, *J* = 4.6 Hz, C^4H), 1.68 (2 H, m, C^3H + C^5H), 1.89 (2 H, m, C^3H + C^5H), 2.00 (3 H, s, CH_3CO), 2.27 (2 H, ddd, *J* = 11.1, 9.8 and 3.9 Hz, C^2H + C^6H); ^{13}C NMR δ 18.44, 21.25, 27.89, 30.63, 39.86, 46.76, 87.95, 170.68; MS *m/z* 43 (100), 140 (94), 125 (64), 122 (52), 70 (46), 182 (M^+, 1).

(*RS*)-(*E*)-4-Chloro-2-pentene (4g). Compound 4g[53] was obtained as a colourless liquid (92% yield, bp 95°C) containing some 15% of the (*Z*)-isomer:[53a] IR (film) 3010w, 2960s, 2945s, 2900m, 1667w, 1447s, 1372m, 1288m, 1265w, 1211s, 1160w, 1013s, 960s, 886w, 738w, 642s cm^{-1}; ^1H NMR δ 1.57 (3 H, d, *J* = 6.6 Hz, CH_3CCl), 1.70 (3 H, dt, *J* = 5.5 and 0.5 Hz, CH_3C=), 4.52 (1 H, dqu, *J* = 6.6 and 0,8 Hz, CHCl), 5.59-5.81 (2 H, m, (*E*) CH=CH); ^{13}C NMR δ 17.25, 25.27, 58.22, 127.07, 133.33; MS *m/z* 69 (100), 41 (83), 39 (62), 53 (62), 49 (49), 104 (M^+, 33), 106 (M^+, 11). (*RS*)-(*Z*)-4-Chloro-2-pentene: ^1H NMR δ 1.56 (3 H, d, *J* = 6.6 Hz, CH_3CCl), 1.70 (3 H, dt, *J* = 5.5 and 0.5 Hz, CH_3C=), 4.89 (1 H, dqu, *J* = 6.6 and 2.3

Hz, CHCl), 5.50-5.58 (2 H, m, (*Z*) CH=CH); ^{13}C NMR δ 12.74, 25.66, 52.35, 126.31, 132.70.

(*Z*)-2-Hexen-1-yl Acetate (3i). Compound 3i[54] was obtained (88% yield) as a colourless liquid: bp 116°C/28660 Pa; IR (film) 3000w, 2930w, 2900w, 2845w, 1738s, 1650w, 1453w, 1370m, 1228s, 1022m, 960w, 603w cm^{-1}; ^{1}H NMR δ 0.91 (3 H, t, *J* = 7.2 Hz, CH_3), 1.41 (2 H, m, $MeCH_2$), 2.05 (3 H, s, CH_3CO), 2.09 (2 H, app q, $EtCH_2$), 4.62 (2 H, d, *J* = 6.0 Hz, $AcOCH_2$), 5.59 (2 H, sym app m, CH=CH); ^{13}C NMR δ 13.33, 20.61, 22.30, 29.24, 60.05, 123.33, 134.77, 170.53; MS *m/z* 43 (100), 67 (62), 82 (55), 41 (52), 39 (51), 142 (M^+, 0.5).

(*RS*)-1-Hexen-3-yl Acetate (3j). Compound 3j[55] was obtained (87% yield) as a yellowish liquid: bp 105°C/22661 Pa; IR (film) 3050w, 2930s, 2905m, 2845m, 1735s, 1642w, 1462w, 1453w, 1420w, 1367s, 1235s, 1113w, 1082w, 1045w, 1017m, 986m, 965m, 923m, 750w, 618w, 602w cm^{-1}; ^{1}H NMR δ 0.92 (3 H, t, *J* = 7.2 Hz, CH_3), 1.35 (2 H, m, $MeCH_2$), 1.60 (2 H, m, $EtCH_2$), 2.06 (1 H, s, CH_3CO), 5.10-5.31 (3 H, m, AcOCH + CH_2=C), 5.77 (1 H, sym app m, *J* = 17.4, 10.4 and 6.3 Hz, C-CH=C); ^{13}C NMR δ 13.62, 18.17, 20.99, 36.14, 74.41, 116.25, 136.51, 170.10; MS *m/z* 43 (100), 67 (45), 100 (44), 99 (41), 41 (31), 142 (M^+, 0.02).

(*RS*)-3-Chlorocyclohexene (4k). Compound 4k[56] was obtained (78% yield) as a colourless liquid: bp 89°C/16663 Pa; IR (film) 3005m, 2920s, 2840w, 2810w, 1640w, 1445w, 1435m, 1390w, 1253w, 1230w, 1219m, 1087w, 1034w, 992w, 918w, 864s, 826w, 740s, 724w, 610w, 528m cm^{-1}; ^{1}H NMR δ 1.55-2.14 (6 H, m, CH_2), 4.61 (1 H, m, CHCl), 5.83 (2 H, m, CH=CH); ^{13}C NMR δ 18.22, 24.51, 32.24, 55.23, 127.91, 131.02; MS *m/z* 81 (100), 79 (81), 80 (53), 39 (51), 53 (48), 116 (M^+, 26), 118 (M^+, 8).

(*RS*)-(1-Chloroethyl)benzene (4n). Compound 4n was obtained[57] (93% yield) as a colourless liquid: bp 72°C/2133 Pa; IR (film) 3035w, 3000w, 2950m, 2900w, 1491m, 1451s, 1375w, 1230m, 1046m, 1024m, 967w, 910w, 776w, 760s, 692s, 640m, 612w cm^{-1}; ^{1}H NMR δ 1.80 (3 H, d, *J* = 6.8 Hz, CH_3), 5.05 (1 H, q, *J* = 6.8 Hz, CHCl), 7.19-7.42 (5 H, m, Ph-H); ^{13}C NMR δ 26.44, 58.66, 126.41, 128.14, 128.53, 142.72; MS *m/z* 105 (100), 51 (29), 140 (M^+, 28), 77 (27), 79 (26), 142 (M^+, 9).

(1-Chloro-1-methylethyl)benzene (4o). Compound 4o[58] was obtained (82% yield) as a colourless liquid: bp 30°C/20 Pa; IR (film) 3060w, 3040w, 3005w, 2955s, 2900w, 1490m, 1443s, 1381w, 1365w, 1255m, 1123s, 1095s, 1071m, 1027w, 900w, 761s, 742m, 694s, 620w, 609s cm^{-1}; ^{1}H NMR δ 1.97 (6 H, s, CH_3), 7.20-7.39 (3 H, m, Ph-H), 7.53-7.61 (2 H, m, Ph-H); ^{13}C NMR δ 34.22, 69.54, 125.39, 127.50, 128.18, 146.16; MS *m/z* 119 (100), 91 (70), 41 (34), 51 (29), 77 (23), 154 (M^+, 8), 156 (M^+, 3). On storage at rt, the product underwent slow decomposition with evolution of HCl.

α-Phenylbenzenemethyl Acetate (3p). The preparation of compound 3p has been reported elsewhere.[59]

(*RS*)-1-(Chlorophenylmethyl)-4-methoxybenzene (4q). Compound 4q was obtained (79% yield, bp 138°C/30 Pa) as a colourless oil which solidified on cooling: mp 61°C;[60] IR 3000w, 2925w, 2805w, 1604s, 1578w, 1504s, 1447m, 1300m, 1246s, 1170s, 1108w, 1028s, 840w, 804m, 777w, 725m, 695s, 627w, 605m, 551m cm^{-1}; ^1H NMR δ 3.78 (3 H, s, CH_3O), 6.12 (1 H, s, CHCl), 6.86 (2 H, sym app m, MeOPh-H), 7.26-7.45 (7 H, m, MeOPh-H + Ph-H); ^{13}C NMR δ 55.27, 64.18, 113.87, 127.66, 127.93, 128.46, 129.10, 133.36, 141.20, 159.31; MS *m/z* 197 (100), 153 (41), 198 (35), 165 (32), 152 (31), 232 (M^+, 11), 234 (M^+, 4).

(*RS*)-4-Nitro-α-phenylbenzenemethyl Acetate (3r). Compound 3r was obtained as a colourless solid (82% yield): mp 83-85°C/hexane-Et_2O);[61] IR 2940w, 1731s, 1602m, 1591m, 1510s, 1488m, 1446w, 1342s, 1223s, 1186m, 1106w, 1029s, 1010s, 983w, 930w, 916w, 869w, 841m, 820m, 750m, 697s, 620w cm^{-1}; ^1H NMR δ 2.19 (3 H, s, CH_3CO), 6.92 (1 H, s, AcOCH), 7.29-7.38 (5 H, m, Ph-H), 7.52 (2 H, sym app m, O_2NPh-H), 8.19 (2 H, sym app m, O_2NPh-H); ^{13}C NMR δ 21.08, 75.90, 123.76, 127.18, 127.60, 128.56, 128.81, 138.77, 147.29, 147.39, 169.69; MS *m/z* 165 (100), 211 (88), 43 (69), 229 (54), 164 (51), 271 (M^+, 26).

(*RS*)-1-(Chlorophenylmethyl)-4-nitrobenzene (4r). Compound 4r was prepared essentially according to a described procedure[62] and obtained as yellowish crystals (76% yield): mp 43°C; IR 3045w, 1603m, 1554w, 1517s, 1487m, 1449m, 1345s, 1259w, 1212w, 1178w, 1108m, 1072w, 1027w, 1011w, 866m, 832s, 812s, 746s, 713s, 697s, 662w, 594m cm^{-1}; ^1H NMR δ 6.17 (1 H, s, PhCH), 7.28-7.45 (5 H, m, Ph-H), 7.60 (2 H, sym app m, O_2NPh-H), 8.21 (2 H, sym app m, O_2NPh-H); ^{13}C NMR δ 62.69, 123.79, 127.65, 128.67, 128.71, 128.91, 139.67, 147.44, 147.88; MS *m/z* 212 (100), 165 (88), 166 (63), 82 (39), 213 (30), 247 (M^+, 10), 249 (M^+, 3).

1-Chloro-1,1-diphenylethane (4s). Compound 4s[63] was detected (54%) in the reaction mixture accompanied by a considerable amount (46%) of the corresponding elimination product and was not isolated: ^1H NMR δ 2.30 (3 H, s, CH_3), 7.25-7.50 (10 H, m, Ph-H). Upon distillation of the oily residue obtained after evaporation of the solvents, an 88% yield of 1,1-diphenylethene was obtained.[9,63b]

9H-Fluoren-9-yl Acetate (3u). Compound 3u [64,65a] was obtained by refluxing 9H-fluoren-9-ol (2u, 11 mmol) in Ac_2O (106 mmol) during 3 h. After evaporation of AcOH and excess Ac_2O at reduced pressure, the oily residue was dissolved into Et_2O (20 mL), washed with H_2O (3 x 20 mL), dried over Na_2SO_4 and concentrated to a small volume. Upon addition of hexane a white solid was obtained (77% yield): mp 71°C); IR 3030w, 3000w,

2880w, 1725s, 1467w, 1440m, 1360m, 1302w, 1225s, 1177w, 1150w, 1090w, 1018s, 981m, 922m, 872w, 755s, 745s, 735s, 646m, 618w, 600w, 579w, 539m cm^{-1}; ^1H NMR δ 2.17 (3 H, s, CH_3CO), 6.78 (1 H, s, AcOCH), 7.27 (2 H, td, *J* = 7.4 and 1.3 Hz, Fl-H), 7.39 (2 H, tdd, *J* = 7.5, 1.3 and 0.5 Hz, Fl-H), 7.54 (2 H, dq, *J* = 7.4 and 0.8 Hz, Fl-H), 7.65 (2 H, dm, *J* = 7.4 Hz, Fl-H); ^{13}C NMR δ 22.22, 75.11, 120.00, 125.85, 127.81, 129.45, 140.99, 141.99, 171.75; MS *m/z* 182 (100), 181 (71), 165 (54), 224 (M^+, 38), 152 (27).

9-Chloro-9H-fluorene (4u). Compound 4u[65] was obtained (84% yield) as a brownish solid: mp 84°C/hexane; IR 3005w, 1605w, 1473w, 1444s, 1303m, 1196s, 1022w, 1000w, 941w, 933w, 858s, 794w, 727s, 672s, 640m, 616m cm^{-1}; ^1H NMR δ 5.80 (1 H, s, CHCl), 7.38 (4 H, m, Fl-H), 7.66 (4 H, m, Fl-H); ^{13}C NMR δ 57.50, 120.11, 125.80, 127.99, 129.33, 139.97, 143.75; MS *m/z* 165 (100), 82 (94), 200 (M^+, 52), 163 (49), 164 (32), 202 (M^+, 26).

9-Chloro-9-methyl-9H-fluorene (4v). Compound 4v was present in the reaction mixture accompanied by a minor amount (10%) of 9-methylene-9H-fluorene.[66] After dilution with pentane (50 mL), the solution was washed with H_2O (3 x 20 mL), dried over Na_2SO_4 and the solvent distilled off. The chloride 4v was isolated as a yellowish oil which failed to crystallize[67] and underwent slow decomposition on storage at rt in the dark: IR (film) 3040w, 2950w, 2900w, 1449s, 1435m, 1372w, 1293m, 1238w, 1206m, 1154w, 1109w, 1053m, 1040m, 1026w, 938w, 807w, 780w, 761s, 739s, 728s, 661s, 619w, 567w cm^{-1}; ^1H NMR δ 2.05 (3 H, s, CH_3), 7.36 (4 H, sym app m, Fl-H), 7.63 (4 H, sym app m, Fl-H); ^{13}C NMR δ 29.68, 69.79, 120.14, 123.79, 128.24, 129.17, 138.21, 148.63; MS *m/z* 179 (100), 178 (57), 89 (24), 76 (21), 152 (18), 214 (M^+, 8), 216 (M^+, 2). The oily residue was dissolved in benzene (10 mL) and treated with MeOH (10 mL); after 24 h at rt a white solid separated (68% yield) which was identified as 9-methoxy-9-methyl-9H-fluorene:[68] mp 88°C; IR 3015w, 2960m, 2910m, 1445s, 1360w, 1291w, 1247s, 1215w, 1111s, 1062m, 1043m, 880w, 764s, 732s, 599m cm^{-1}; ^1H NMR δ 1.69 (3 H, s, CH_3), 2.75 (3 H, s, CH_3O), 7.35 (4 H, sym app m, Fl-H), 7.49 (2 H, app m, Fl-H), 7.65 (2 H, app m, Fl-H); ^{13}C NMR δ 26.47, 51.56, 84.86, 119.91, 123.64, 127.77, 128.82, 140.06, 146.52; MS *m/z* 179 (100), 195 (72), 178 (45), 210 (M^+, 39), 180 (33).

9-Chloro-9-phenyl-9H-fluorene (4w). Compound 4w was obtained (81% yield) as a brownish solid: mp 79°C/petroleum ether 40-60°C;[69] IR 3040w, 1596w, 1578w, 1491m, 1443s, 1282w, 1226w, 1208w, 1152m, 1092w, 1031w, 1000w, 918w, 872m, 838m, 737s, 720s, 691s, 670s, 623s cm^{-1}; ^1H NMR δ 7.15-7.51 (11 H, m, Ar-H), 7.69 (2 H, ddd, *J* = 7.4, 1.4 and 0.7 Hz, Ar-H); ^{13}C NMR δ 74.68, 120.23, 125.51, 126.47, 127.89, 128.32, 128.54, 129.19, 138.77, 141.17, 149.33; MS *m/z* 241 (100), 119 (88), 239 (51), 106 (19),

237 (18), 276 (M^+, 11), 278 (M^+, 5).

α-Acetoxy-α-phenylbenzeneacetic Acid (3y), α-Chloro-α-phenylbenzeneacetic Acid (4y), Methyl α-Acetoxy-α-phenylbenzeneacetate (3z) and Methyl α-Chloro-α-phenylbenzeneacetate (4z). The syntheses of compounds 3y,[19] 4y,[59] 3z[19] and 4z[59] have been reported elsewhere.

9-Acetoxy-9H-fluorene-9-carboxylic Acid (3α). Compound 3α[70] was prepared by treating the corresponding hydroxy acid 2α (0.1 mol) with Ac_2O (0.5 mol) at 80°C for 4 h and then pouring the reaction mixture into H_2O (200 mL). The oily residue which separated was dissolved in Et_2O (100 mL), washed with H_2O (5 x 100 mL), dried over Na_2SO_4 and concentrated to a small volume; upon addition of hexane a brownish product crystallized which was collected and dried in vacuo at 70°C over P_4O_{10} (76% yield): mp 201°C; IR 3200-2400m (br), 2835m, 1746s, 1713s, 1697s, 1645w, 1555w, 1538w, 1518w, 1504w, 1447m, 1418w, 1369m, 1280s, 1236s, 1193m, 1152w, 1096w, 1032s, 1002m, 950w, 762w, 730s, 666w cm^{-1}; ^1H NMR δ 2.12 (3 H, s, CH_3CO), 7.29 (2 H, td, *J* = 7.5 and 1.2 Hz, Fl-H), 7.43 (2 H, td, *J* = 7.5 and 1.1 Hz, Fl-H), 7.63 (2 H, app d, *J* = 7.5 Hz, Fl-H), 7.77 (2 H, app d, *J* = 7.5 Hz, Fl-H), 9.27 (1 H, br s, COOH); ^{13}C NMR δ 20.89, 85.39, 120.11, 126.98, 128.35, 130.57, 140.81, 141.21, 171.06, 174.38; MS *m/z* 181 (100), 182 (51), 43 (34), 152 (28), 153 (14), 268 (M^+, 11).

9-Chloro-9H-fluorene-9-carboxylic Acid (4α). Compound 4α was obtained as a brownish solid (66% yield): mp 165°C/ligroine-benzene;[71] IR 3200-2000s (br), 1704s, 1449m, 1403m, 1267s, 1190m, 1153w, 1107w, 982w, 912m, 891m, 748s, 729s, 696w, 660w, 618w cm^{-1}; ^1H NMR δ 7.33 (2 H, td, *J* = 7.4 and 1.4 Hz, Fl-H), 7.42 (2 H, td, *J* = 7.4 and 1.4 Hz, Fl-H), 7.64 (2 H, ddd, *J* = 7.2, 1.5 and 0.9 Hz, Fl-H), 7.71 (2 H, ddd, *J* = 7.2, 1.5 and 0.9 Hz, Fl-H), 9.43 (1 H, br s, COOH); ^{13}C NMR δ 69.02, 120.33, 126.07, 128.48, 130.35, 139.89, 142.84, 174.14; MS *m/z* 165 (100), 199 (47), 164 (39), 163 (38), 166 (21), 244 (M^+, 18), 246 (M^+, 5).

Methyl 9-Acetoxy-9H-fluorene-9-carboxylate (3β). Compound 3β was obtained as a white solid (85% yield): mp 147°C/EtOH;[72] IR 2920w, 1740s, 1448m, 1368m, 1300m, 1267s, 1229s, 1198s, 1100w, 1037s, 1013s, 968w, 909w, 887w, 807w, 766s, 738s, 717w, 677w, 621w, 592w, 552m cm^{-1}; ^1H NMR δ 2.15 (3 H, s, CH_3CO), 3.70 (3 H, s, CH_3O), 7.30 (2 H, td, *J* = 7.5 and 1.3 Hz, Fl-H), 7.44 (2 H, td, *J* = 7.5 and 1.3 Hz, Fl-H), 7.65 (2 H, ddd, *J* = 7.4, 1.2 and 0.7 Hz, Fl-H), 7.77 (2 H, ddd, *J* = 7.4, 1.2 and 0.7 Hz, Fl-H); ^{13}C NMR δ 21.09, 53.00, 85.71, 120.05, 126.89, 128.25, 130.36, 141.15, 141.35, 169.36, 171.08; MS *m/z* 181 (100), 43 (19), 152 (15), 182 (14), 282 (M^+, 12).

(*RS*)-3-Chloro-3-*d*-cyclohexene (16) and (*RS*)-3-Chloro-1-*d*-cyclohexene (17). Alcohol 15 (20.0 mmol) was allowed to react with AcCl (1a, 22.0

mmol) in CH_2Cl_2 (2.4 mL) in the usual manner. The reaction mixture was analyzed after 10 min at rt: compounds 16 and 17 were both present in a relative percentage 53.6 to 46.4. Quenching by CH_2N_2 of the reaction mixture, followed by fractional distillation gave a colourless liquid[73] (80% yield): bp 50°C/3599 Pa; IR (film) 3002w, 2908s, 2840m, 2802m, 2225w, 2095m, 1650m, 1433m, 1362m, 1335w, 1250w, 1219m, 1173w, 1158m, 1116w, 1067w, 992w, 951m, 918s, 890m, 854w, 833w, 791w, 719s, 661s, 605w, 520w cm^{-1}; ^1H NMR δ 1.63 (~ 1 H, dtd, J = 18.1, 5.0 and 0.6 Hz, CDCl-C=C-CH_2), 1.71-2.23 (~ 5 H, m, CH_2), 4.61 (0.54 H, sym app m, CHCl), 5.75-5.93 (1.46 H, m, CH=CH + CD=CH); ^{13}C NMR δ 18.25, 24.45, 24.59, 32.17, 32.31, 54.98 (t, J = 23.6 Hz), 55.32 (t, J = 1.2 Hz), 127.86, 130.81 (t, J = 24 Hz), 131.20.

Preparation of Esters 3li, 3nd-h and 3pd-g

The appropriate acyl chloride (1, 12.0 mmol) solution in Et_2O (10.0 mL) was added dropwise under efficient stirring to a chilled ethereal solution (20.0 mL) of the alcohol 2 of choice (10.0 mmol) and triethylamine (12.0 mmol). The mixture was refluxed during 4-6 h, then thoroughly washed with 5% aqueous $NaHCO_3$ and dried over Na_2SO_4. The produced esters 3li, 3nd-h and 3pd-g were purified by conventional distillation or crystallization.

Benzenemethyl 4-Methylbenzoate (3li). Compound 3li was obtained (88% yield) as a white solid: mp 46°C/pentane;[74] IR 3000w, 1700s, 1607m, 1451w, 1368m, 1306w, 1264s, 1210w, 1173m, 1097s, 1075m, 1014m, 938w, 904m, 839m, 750s, 699m, 588w, 520w cm^{-1}; ^1H NMR δ 2.37 (3 H, s, CH_3), 5.34 (2 H, s, $PhCH_2$), 7.21 (2 H, sym app m, MePh-H), 7.29-7.48 (5 H, m, Ph-H), 7.96 (2 H, sym app m, MePh-H); ^{13}C NMR δ 21.56, 66.39, 127.32, 128.02, 128.08, 128.48, 129.00, 129.65, 136.13, 143.61, 166.39; MS *m/z* 119 (100), 91 (84), 65 (33), 226 (M^+, 32), 120 (15).

(*RS*)-α-Methylbenzenemethyl 2,2-Dimethylpropanoate (3nd). The previously unknown 3nd was obtained (81% yield) as a colourless liquid: bp 40°C/10 Pa; IR (film) 2980m, 1730s, 1479m, 1452w, 1395w, 1369w, 1281s, 1160s, 1064m, 1029m, 1005w, 995w, 970w, 760w, 699m cm^{-1}; ^1H NMR δ 1.21 (9 H, s, CH_3-C-CO), 1.50 (3 H, d, J = 6.6 Hz, CH_3-C-Ph), 5.85 (1 H, q, J = 6.6 Hz, PhCH), 7.26-7.36 (5 H, m, Ph-H); ^{13}C NMR δ 22.30, 26.99, 38.58, 71.79, 125.64, 127.51, 128.33, 177.45; MS *m/z* 105 (100), 57 (59), 41 (19), 104 (17), 77 (14), 206 (M^+, 9).

(*RS*)-α-Methylbenzenemethyl Trichloroacetate (3ne). The previously unknown 3ne was obtained (94% yield) as a colourless liquid: bp 78°C/10 Pa; IR (film) 2992w, 1769s, 1496w, 1450w, 1379w, 1243s, 1210m, 1060m, 1028m, 1003w, 990m, 968m, 882s, 826s, 760m, 699s, 682s cm^{-1}; ^1H NMR δ 1.68

(3 H, d, J = 6.6 Hz, CH_3-C-Ph), 5.98 (1 H, q, J = 6.6 Hz, PhCH), 7.32-7.44 (5 H, m, Ph-H); ^{13}C NMR δ 21.81, 78.17, 90.07, 125.95, 128.60, 128.70, 139.44, 161.02; MS *m/z* 105 (100), 104 (53), 77 (24), 36 (19), 51 (14), 266-270 (M^+, cluster, 10).

(*RS*)-α-Methylbenzenemethyl Benzoate (3nf). Compound 3nf[75] was obtained (76% yield) as a colourless liquid: bp 120°C/267 Pa; IR (film) 3035w, 3000w, 2945m, 2900w, 1717s, 1601w, 1583w, 1493m, 1451s, 1375w, 1312w, 1267s, 1173w, 1108m, 1062m, 1048m, 1024m, 968w, 910w, 760s, 710s, 693s, 640w, 612w, 567w, 517w cm^{-1}; ^{1}H NMR δ 1.67 (3 H, d, J = 6.6 Hz, CH_3), 6.14 (1 H, q, J = 6.6 Hz, PhCH), 7.23-7.60 (8 H, m, Ph-H), 8.08 (2 H, sym app m, Ph-H); ^{13}C NMR δ 22.36, 72.86, 125.99, 127.83, 128.28, 128.49, 129.58, 130.46, 132.86, 141.73, 165.75; MS *m/z* 105 (100), 104 (70), 77 (66), 226 (M^+, 35), 51 (25).

(*RS*)-α-Methylbenzenemethyl 4-Nitrobenzoate (3ng). Compound 3ng was obtained (93% yield) as a yellowish solid: mp 44°C (H_2O/EtOH);[76] IR 2990w, 1720s, 1606w, 1521s, 1493w, 1450w, 1350s, 1324m, 1275s, 1210w, 1100s, 1060s, 1026w, 1010m, 989m, 918w, 870m, 843m, 779w, 765m, 714s, 699s cm^{-1}; ^{1}H NMR δ 1.71 (3 H, d, J = 6.6 Hz, CH_3-C-Ph), 6.16 (1 H, q, J = 6.6 Hz, PhCH), 7.28-7.50 (5 H, m, Ph-H), 8.26 (4 H, sym app m, O_2NPh-H); ^{13}C NMR δ 22.20, 74.19, 123.50, 126.11, 128.27, 128.68, 130.73, 135.85, 140.93, 150.48, 163.91; MS *m/z* 104 (100), 105 (85), 150 (56), 151 (49), 77 (35), 271 (M^+, 20).

(*RS*)-α-Methylbenzenemethyl 4-Methoxybenzoate (3nh). The previously unknown 3nh was obtained (53% yield) as a colourless oil: bp 110°C/10 Pa; IR (film) 2980w, 1758s, 1605s, 1580w, 1510m, 1450w, 1418w, 1316w, 1255m, 1167s, 1098m, 1060w, 1027m, 843w, 768m, 698m, 612w cm^{-1}; ^{1}H NMR δ 1.65 (3 H, d, J = 6.6 Hz, CH_3-C-Ph), 3.82 (3 H, s, CH_3O), 6.11 (1 H, q, J = 6.6 Hz, PhCH), 6.90 (2 H, sym app m, MeOPh-H), 7.23-7.48 (5 H, m, Ph-H), 8.04 (2 H, sym app m, MeOPh-H); ^{13}C NMR δ 22.42, 55.32, 72.46, 113.51, 122.87, 125.95, 126.15, 126.23, 127.73, 128.45, 131.60, 141.96, 163.28, 165.49; MS *m/z* 135 (100), 105 (90), 77 (68), 104 (68), 256 (M^+, 67).

α-Phenylbenzenemethyl 2,2-Dimethylpropanoate (3pd). The previously unknown 3pd was obtained (75% yield) as a white solid: mp 65°C (H_2O/EtOH); IR 2980m, 1727s, 1494w, 1479w, 1450m, 1396w, 1367w, 1279m, 1150s, 1082w, 1033w, 983w, 913w, 744m, 702s, 650w cm^{-1}; ^{1}H NMR δ 1.26 (9 H, s, CH_3-C-CO), 6.82 (1 H, s, PhCH), 7.20-7.40 (10 H, m, Ph-H); ^{13}C NMR δ 27.10, 38.87, 76.53, 126.85, 127.72, 128.45, 140.57, 177.25; MS *m/z* 166 (100), 167 (89), 165 (82), 57 (51), 41 (23), 268 (M^+, 17).

α-Phenylbenzenemethyl Trichloroacetate (3pe). Compound 3pe was obtained (85% yield) as a white solid: mp 51°C (H_2O/EtOH);[77] IR 3070w, 3032w, 1768s, 1493m, 1446w, 1235s, 1187m, 1079w, 1030w, 990s, 952m, 921w,

843s, 818m, 752m, 735m, 698s, 672s cm^{-1}; ^1H NMR δ 6.93 (1 H, s, PhCH), 7.27-7.45 (10 H, m, Ph-H); ^{13}C NMR δ 82.00, 89.99, 127.01, 128.60, 128.71, 138.17, 160.78; MS *m/z* 166 (100), 167 (74), 165 (66), 152 (19), 83 (18), 328-332 (M^+, cluster, 8).

α-Phenylbenzenemethyl Benzoate (3pf). Compound 3pf was obtained (66% yield) as a white solid: mp 88°C (hexane);[78] IR 3061w, 3038w, 1711s, 1598w, 1583w, 1493w, 1451m, 1317m, 1265s, 1178m, 1109s, 1070m, 1021m, 968s, 930w, 898w, 758m, 749m, 702s cm^{-1}; ^1H NMR δ 7.13 (1 H, s, PhCH), 7.21-7.48 (12 H, m, Ph-H + OCPh-H), 7.54 (1 H, sym app tt, OCPh-H), 8.14 (2 H, sym app m, OCPh-H); ^{13}C NMR δ 76.02, 126.72, 127.56, 128.04, 128.16, 129.38, 129.78, 132.75, 139.86, 165.14; MS *m/z* 166 (100), 165 (80), 105 (46), 167 (32), 77 (32), 288 (M^+, 13).

α-Phenylbenzenemethyl 4-Nitrobenzoate (3pg). Compound 3pg was obtained (89% yield) as a yellowish solid: mp 131°C (hexane/Et_2O);[79] IR 3118w, 3060w, 1721s, 1606w, 1527s, 1494w, 1449w, 1346s, 1280s, 1260s, 1187w, 1115s, 1102s, 1011m, 962m, 916w, 899w, 872w, 853w, 842w, 783w, 761m, 745m, 718m, 700s cm^{-1}; ^1H NMR δ 7.14 (1 H, s, PhCH), 7.27-7.48 (10 H, m, Ph-H), 8.30 (4 H, app s, O_2NPh-H); ^{13}C NMR δ 78.49, 123.60, 127.11, 128.28, 128.68, 130.87, 135.54, 139.50, 150.61, 163.72; MS *m/z* 165 (100), 166 (97), 167 (38), 183 (27), 152 (17), 333 (M^+, 3).

Reactions between 2 or 3 and HCl

α-Phenylbenzenemethanol (2p, 5.0 mmol) was admixed with CH_2Cl_2 (0.6 mL) and the slurry was saturated with gaseous dry HCl at 0°C. After 10 min the reaction became homogeneous and H_2O started to separate eventually: chlorodiphenylmethane (4p) was the only product detected in the reaction mixture.

Under identical conditions were run the reactions between either 2y or 2z and HCl: no reaction at all ensued even after 24 h at rt. Addition of AcOH (1.0 mL) to the mixture did not change matters.

Benzenemethyl acetate (3l, 5.0 mmol) and hexyl acetate (3a, 5.0 mmol) did not react at all with a saturated HCl solution in CH_2Cl_2 (0.6 mL) during 24 h at rt.

A solution of α-phenylbenzenemethyl acetate (3p, 5.0 mmol) in CH_2Cl_2 (0.6 mL) was saturated with dry HCl at 0°C: after 30 min a 95% conversion into the corresponding chloride 4p was observed, after 1 h the conversion was complete.

Competitive reactions of the systems 2p-3p (5.0 mmol of each) and Ph(Me)CHOH-PhMeCHOAc (2n-3n, 5.0 mmol of each) in CH_2Cl_2 (1.0 mL) containing ca. 5.0 mmol of HCl at 0°C gave ca. 70% transformation of both alcohols into the corresponding chlorides 4p and 4n, but the acetates 3p

and 3n were left unchanged.

α-Acetoxy-α-phenylbenzeneacetic acid (3y, 5.0 mmol, anhyd[19]) in 3.0 mL CH_2Cl_2 was treated with bubbling dry HCl at 0°C during 1 h: at 30 min some 8% of 3y was transformed into the corresponding chloride (4y), after 1 h the percentage increased to 26%. The evolution of the obtained solution kept at rt recorded a 2 h 45% conversion which eventually rose to 72% at 24 h.

Reactions of 3 with 1

1,1-Dimethylethyl acetate (3c, 10.0 mmol) in CH_2Cl_2 (1.2 mL) containing 1a (11.2 mmol) did not react after 1 h at rt. When the solvent was evaporated and the mixture was refluxed during 24 h a 58% conversion into the chloride 4c was observed.

α-Phenylbenzenemethyl acetate (3p, 2.0 mmol) in benzene (1.0 mL)[6] containing 1a (6.3 mmol) was refluxed during 4 h to yield 6% of the corresponding chloride 4p. The same result was obtained using 1a (7.0 mmol) or $CHCl_3$ (0.25 mL) as a solvent.

Under analogous conditions hexyl acetate (3a) and benzenemethyl acetate (3l) did not undergo any transformation.

α-Acetoxy-α-phenylbenzeneacetic acid (3y, 2.0 mmol, anhyd[19]) suspended in CH_2Cl_2 (0.5 mL) containing 1a (2.2 mmol) underwent chlorination to 4y as follows: 5% 4y after 1 h at rt, 19% at 2 h (homogeneous reaction mixture), 33% at 4 h, 54% at 24 h and 65% after 3 d.

Competition Reactions

Benzenemethanol (2l, 5.0 mmol) and α-phenylbenzenemethanol (2p, 5.0 mmol) in CH_2Cl_2 (0.6 mL) containing 1a (5.0 mmol) at rt yielded: at 5 min 45% benzenemethyl acetate (3l), 5% chloromethylbenzene (4l), 9% α-phenylbenzenemethyl acetate (3p) and 74% chlorodiphenylmethane (4p); at 1 h 76% 3l, 5% 4l, 7% 3p and 93% 4p.

α-Phenylbenzenemethanol (2p, 5.0 mmol) in CH_2Cl_2 (0.6 mL) containing 1a (5.6 mmol) and 1b (5.6 mmol) after 1h at rt gave bromodiphenylmethane (4pb, 91%) and chlorodiphenylmethane (4p, 9%); at 24 h these figures became respectively 87 and 13%.

In another experiment, MeOH (5.0 mmol) and H_2O (5.0 mmol) in anhyd THF (0.6 mL) containing 1a (4.9 mmol) after 3 min at 0°C gave: 80% AcOMe and 20% AcOH (5a); when the alcohol was benzenemethanol (2l), under the same conditions, 61% benzenemethyl acetate (3l) and 39% 5a was obtained.

Alcohol 2l (5.0 mmol) and H_2O (5.0 mmol) in anhyd THF (0.6 mL) containing 4-methylbenzoyl chloride (1i, 4.7 mmol) after 24 h at rt gave: 37% unreacted 1i, 23% of the corresponding acid 5i and 40% benzenemethyl

4-methylbenzoate (3li); after 48 h at rt: 15% 1i, 33% 5i and 52% 3li.

Other Tests

α-Phenylbenzenemethanol (2p, 5.0 mmol) in CH_2Cl_2 (0.6 mL) containing AcOH (5a, 5.0 mmol) was left at rt during 24 h: no ester 3p was formed.

Chlorodiphenylmethane (4p) was treated as above: after 1 h some 2% ester 3p was formed; no change was observed after 24 h.

Compound 4p was treated as above using trichloroacetic acid (5e) instead of 5a: after 1 h the mixture equilibrated to 11% of the corresponding ester 3pe.

A mixture of 1a (1.4 mmol) and 5a (1.4 mmol) in CD_2Cl_2 (0.3 mL) after 10 min at rt equilibrated yielding Ac_2O (6%).

Solvent Effect in the Reactions between 1a and 2

Reactions and experimental conditions are described in Table I.

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