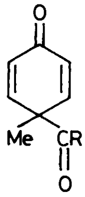
Dienone–Phenol Rearrangements of 3-Acylcyclohexa-2,5-dienones: Kinetics and Mechanism

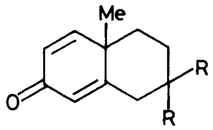
Gary Goodyear and Anthony J. Waring*
Department of Chemistry, University of Birmingham, PO Box 363, Birmingham B15 2TT

The dienone–phenol rearrangements of 3-acetyl-4,4-dimethyl-, 3-ethoxycarbonyl-4,4-dimethyl-, and 3-acetyl-4,4,5-trimethylcyclohexa-2,5-dienones have been studied. The 3-acetyl and 3-ethoxycarbonyl compounds rearrange under acidic conditions to give the 3-acyl-4,5-dimethylphenols, *via* a 4–5-methyl migration. Kinetic measurements were made which also allowed the protonation (basicity) behaviour of the 3-acetyl-4,4-dimethyl compound to be determined. The acetyl group considerably reduces the basicity of the dienone. At high acidities, where the dienone is largely protonated, it rearranges four times faster than the 4,4-dimethyl-, and 100 times faster than the 3,4,4-trimethyl dienone, showing the acetyl group to enhance the reactivity of the cation. At low acidities the amount of reactive cation, and thus the observed rate of rearrangement, is small. The effect of the acetyl group on the basicity and reactivity are attributed to its destabilising the dienone cation relative to the neutral dienone, and relative to the cation produced by rearrangement. The 3-ethoxycarbonyl group shows similar behaviour. The acceleration of rearrangement is also found for 3-acetyl-4,4,5-trimethylcyclohexa-2,5-dienone, the cation of which reacts slowly, but still at least 60 times faster than the 3,4,4,5-tetramethyl analogue.

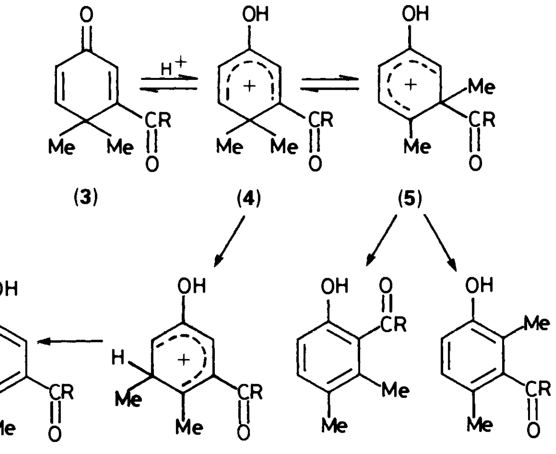
We have been interested for some time in acyl cyclohexadienones, and in their potential use in measuring the migratory aptitudes (migration tendencies) of acyl groups in carbocation rearrangements. Our previous studies have centred on 4-acyl-4-methylcyclohexa-2,5-dienones (**1**)[1,2] and (**2**).[3] Unfortunately these undergo ready nucleophilic cleavage to 4-methylphenols and carboxylic acids, or retro-Fries rearrangements to 4-methylphenyl esters when treated with acids.[1–3] We hoped that an alternative approach might succeed. In this the species needed for rearrangement would not be the cation of a molecule such as (**1**) or (**2**) but an ion produced by a prior rearrangement step. We envisaged such a 'switch-on' step where the protonated 3-acyl dienone (**4**) might rearrange to the cation (**5**) (Scheme 1), which then has the acyl and alkyl group in a position where they can migrate competitively. The success of this approach would depend on a number of assumptions, which could not be fully quantified. The first was that the protonated dienone (**4**) should undergo some methyl migration to C-3, the position occupied by the acyl group, and not entirely to the unoccupied C-5. The reasoning and calculations which gave us hope of this are discussed later. The second assumption, again based on our earlier work[4–6] and supported more recently,[7] was that the rearranged cation (**5**) would allow competitive migration of the acyl and methyl groups, giving (**6**) and (**7**), respectively. We expected that the desired migrations to C-2 would be somewhat difficult compared with migration back to C-4, but that they should be irreversible. If the rate of migration of a methyl group from C-4 to C-3 or C-5 were to be too small the 'switch-on' step could be accelerated by using a 4-ethyl instead of the 4-methyl group in the dienone (**3**).[4,6] In the event, we have not been able to obtain measurements of migratory aptitudes of acetyl or ethoxycarbonyl groups, due to unfortunate relative rates for the steps (**4**)–(**5**) and (**4**)–(**8**). We have found, however, that both the acetyl and ethoxycarbonyl groups significantly accelerate the rearrangements, and explain this by their destabilising the initial cations (**4**) relative to the rearranged cations (**5**) and (**8**). More heavily alkylated dienones have also been studied, and show strong acceleration in the same way.



(**1**) R = Me
R = C_6H_5
R = C_6H_4Cl-*p*
R = C_6H_4OMe-*p*



(**2**) R = H
R = Me



Scheme 1.

Kinetic Results.—Rearrangement of 3-acetyl-4,4-dimethylcyclohexa-2,5-dienone (**3**; R = Me) in aqueous sulphuric acid, or in acetic anhydride with sulphuric acid catalysis, gave only 3-acetyl-4,5-dimethylphenol (**9**; R = Me) or its acetate. Kinetic measurements (see Table 1) allowed a plot to be made of the

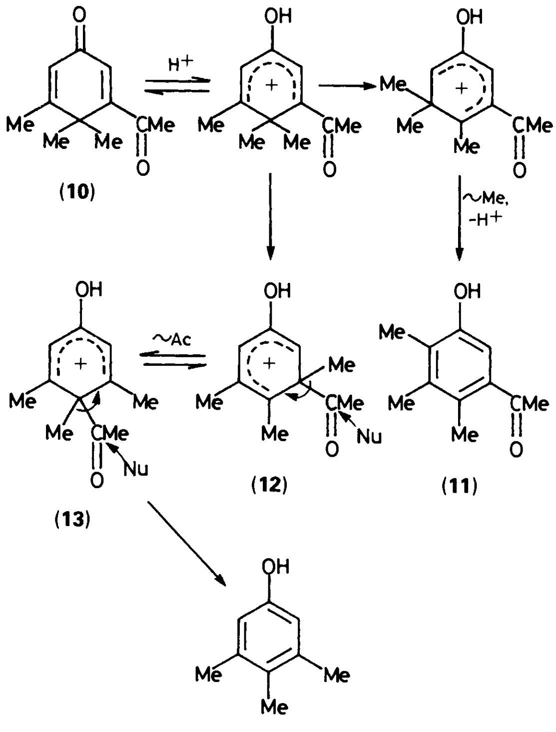
Table 1. Kinetic data for rearrangements

Compound	Medium	%[a]	$-H_0$[b]	T/°C	$\log_{10}(k_{obs}/s^{-1})$
(3; R = Me)	CF_3CO_2H			20	$\leqslant -6.82$[c]
	Aq. H_2SO_4	41.4	2.55	25.0	−5.70
	Aq. H_2SO_4	41.4	2.55	25.0	−5.51
	Aq. H_2SO_4	49.3	3.24	25.0	−5.05
	Aq. H_2SO_4	49.3	3.24	25.0	−5.06
	Aq. H_2SO_4	55.3	3.83	25.0	−4.51
	Aq. H_2SO_4	55.3	3.83	25.0	−4.21
	Aq. H_2SO_4	59.0	4.25	25.0	−4.08
	Aq. H_2SO_4	59.0	4.25	25.0	−4.06
	Aq. H_2SO_4	62.6	4.71	25.0	−3.97
	Aq. H_2SO_4	62.6	4.71	25.0	−3.92
	Aq. H_2SO_4	68.2	5.55	25.0	−3.29
	Aq. H_2SO_4	68.2	5.55	25.0	−3.27
	Aq. H_2SO_4	73.1	6.33	25.0	−2.92
	Aq. H_2SO_4	73.1	6.33	25.0	−2.85
	Aq. H_2SO_4	75.8	6.78	25.0	−2.82
	Aq. H_2SO_4	75.8	6.78	25.0	−2.79
	Aq. H_2SO_4	81.4	7.78	25.0	−2.41
	Aq. H_2SO_4	81.4	7.78	25.0	−2.50
(**10**)	CF_3CO_2H	—	—	35	$\leqslant -7.68$[d]
	H_2SO_4	68.2	5.55	25.0	−6.32
					−6.92[e]
					−6.44[f]
(3; R = OEt)	CF_3CO_2H	—	—	37	−5.61
					−5.70
					−5.65
	H_2SO_4	68.2	5.55	25.0	−3.34

[a] % Acid, w/w. [b] Hammett acidity function values from ref. 13. [c] Based on no detectable (<5%) reaction in 96 h. [d] Based on no detectable (<5%) reaction in 28 days. [e] Migration to C-3. [f] Migration to C-5.

logarithm* of the observed rate constants, k_{obs} against the Hammett acidity function, H_0, and the amide acidity function, H_A, over a good acidity range. The protonation behaviour (basicity) of the dienone could not be determined satisfactorily from the variation of the UV spectrum with acidity, but other results bearing on this will be given later. We were able to convert the measured rates into rate constants for rearrangement of the kinetically important dienone-cation, k_1, as before.[4–6,8] At high acidities the plot of log k_{obs} (=log k_1) *vs*. H_0 or H_A is a straight line, almost parallel to those obtained for 4,4-dimethylcyclohexa-2,5-dienone and the 3,4,4-trimethyl dienone. The offset of the plots shows that the cation of the 3-acetyl-4,4-dimethyl dienone reacts 3.3–4.3 times faster than that of the 4,4-dimethyl dienone, and 90–110 times faster than the 3,4,4-trimethyl dienone at the same acidities.† Our explanation of the acceleration will be given later in this paper.

The rearrangement of 4,4-dimethyl-3-ethoxycarbonylcyclohexa-2,5-dienone (**3**; R = OEt) in aqueous sulphuric acid or in trifluoroacetic acid cleanly gave 4,5-dimethyl-3-ethoxycarbonylphenol (**9**; R = OEt). Kinetic measurements in 68.2% sulphuric acid showed it to react with an observed rate, k_{obs}, which is 90% of that found for the 3-acetyl-4,4-dimethyl dienone, about 50 times faster than the 3,4,4-trimethyl dienone (or its cation), and twice as fast as the 4,4-dimethyl dienone (or its cation) at the same acidity. We believe the 3-acetyl dienone to be nearly completely protonated at this acidity (see later). The 3-ethoxycarbonyl dienone should be more basic (having a less electron-attracting acyl group, measured by the σ^+ value), and thus be more completely protonated. The figures to be discussed later would suggest that, in 68.2% sulphuric acid, the cation of the 3-ethoxycarbonyl dienone should be 1–1.5 times as reactive as implied by the observed constant.



Scheme 2.

In the hope of discouraging methyl migration from C-4 to C-5 we introduced a methyl group at the latter site. We showed before[4,6] that such substitution markedly slows migration to an occupied site, a result which has been confirmed recently by Hünig and his co-workers.[7] The rearrangement of 3-acetyl-4,4,5-trimethylcyclohexa-2,5-dienone (**10**) (Scheme 2) was indeed slow. Preparative rearrangements in aqueous sulphuric acid gave as products 3-acetyl-4,5,6-trimethylphenol (**11**) and 3,4,5-trimethylphenol, in a molar ratio close to 3:1. The former appears to be formed by migration of a methyl group from C-4 to C-5, and then again to C-6. The 3,4,5-trimethylphenol must be formed by migration of a methyl group from C-4 to C-3, to give the ion (**12**) which may be directly de-acetylated, or the acetyl group (assumed to be a fast migrator) may move to C-4, as in (**13**), and be cleaved from there in the usual manner.[1–3] The cleavage must thus be faster than further migration of the acetyl or methyl group forward to C-2. It probably follows that the rate of formation of the trimethylphenol represents the rate of methyl migration from C-4 to C-3, which must be a third or less of the rate of migration to C-5.

Protonation Behaviour of the Dienones.—Estimates of the protonation behaviour of the dienones were gained as follows. For the 3-acetyl-4,4-dimethyl dienone, for which rate constants were measured over a large range of acidity, we used the methods described in ref. 8. Refinement of the constants in equations (1) and (2), and in equations (3) and (4) to optimise the fit to the plots of log k_{obs} against acidity gave the values shown in Table 2. The corresponding kinetic constants are given in Table 3. The fact that the parameter m_A has the value (1.02 ± 0.03) suggests that this dienone acts as an amide base. It is half-protonated at H_A (−3.7 ± 0.1), and has a derived pK

---

* All logarithms are $\log_{10}$.

† The range of these ratios reflects the fact that the line of log k_1 for the cation of the 3,4,4-trimethyl dienone is not quite parallel to those for the 3-acetyl-4,4-dimethyl and 4,4-dimethyl dienones.

Table 2. Basicity parameters for 3-acetyl-4,4-dimethylcyclohexa-2,5-dienone in H_2SO_4 at 25 °C.

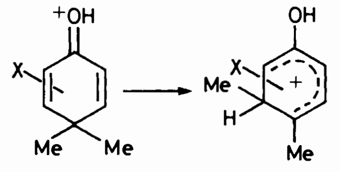
$(H_A)_{\frac{1}{2}}{}^a$	$m_A{}^b$	$(H_0)_{\frac{1}{2}}{}^c$	$m_0{}^d$	pK
(−3.7 ± 0.1)	(1.02 ± 0.03)	(−5.55 ± 0.1)	(0.62 ± 0.05)	(−3.8 ± 0.2)

[a] Half-protonation acidity on amide acidity function, H_A, using the scale of K. Yates, J. B. Stevens, and A. R. Katritzky, *Can. J. Chem.*, 1964, **42**, 1957. [b] See equation (1). [c] Half-protonation acidity on Hammett's acidity scale, H_0, using data from ref. 13. [d] See equation (3).

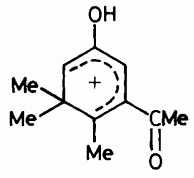
Table 3. Kinetic parameters for 3-acetyl-4,4-dimethylcyclohexa-2,5-dienone in H_2SO_4 at 25 °C.

c^a	$\log k^0_{1,A}{}^a$	d^b	$\log k^0_{1,0}{}^b$
(−0.54 ± 0.03)	(−4.95 ± 0.15)	(−0.20 ± 0.05)	(−4.05 ± 0.2)

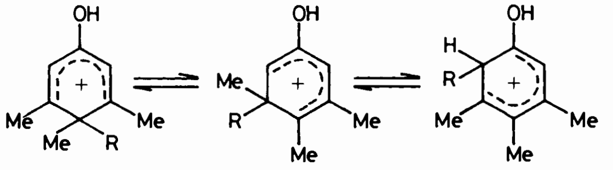
[a] Values in equation (2). [b] Values in equation (4).



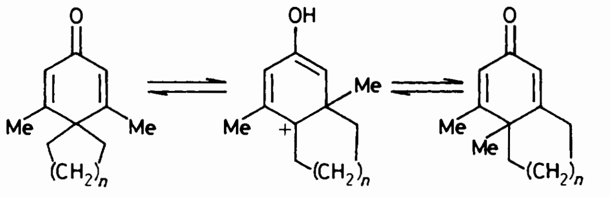
(14) (15)



(21)



(17) (16) (18)



(19) (20)

value (−3.8 ± 0.2). This corresponds to half-protonation in *ca.* 68% sulphuric acid. One may compare the 3,4,4-trimethyl and 4,4-dimethyl dienones, which have half-protonation at H_A (−2.01 ± 0.03), and (−2.37 ± 0.03), corresponding to (40.5 ± 0.6) and (48.0 ± 0.3)% sulphuric acid, with slope parameters, m_A, 1.13 and 1.03, respectively. The 3-acyl group is thus strongly base-weakening, by destabilising the cation (**4**) relative to the neutral dienone.

$$\log[SH^+]/[S] = m_A[(H_A)_{\frac{1}{2}} - H_A] \qquad (1)$$

$$\begin{aligned} d[\text{stoicheiometric substrate}]/dt &= -k_{obs}[\text{stoicheiometric substrate}] \\ &= -k_{obs}[S + SH^+] \\ &= -k_1[SH^+] \\ \therefore k_1 &= k_{obs}(1 + [S]/[SH^+]) \end{aligned}$$

$$\log k_1 = \log k^0_{1,A} + cH_A \qquad (2)$$

Similar equations can be given for use with Hammett's acidity function:

$$\log[SH^+]/[S] = m_0[H_0)_{\frac{1}{2}} - H_0] \qquad (3)$$

$$\log k_1 = \log k^0_{1,0} + dH_0 \qquad (4)$$

The basicity and charge distribution in the 3-ethoxycarbonyl dienone were estimated differently. The ^{1}H NMR spectrum was measured in trifluoroacetic acid (see the Experimental section). Our earlier studies[9] of alkylcyclohexa-2,5-dienones show that complete protonation in aqueous sulphuric acid causes downfield shifts of (1.00 ± 0.05) ppm for 2- and 6-, and (1.44 ± 0.06) ppm for 3- and 5-. Although medium effects may differ between sulphuric and trifluoroacetic acids, Marx believed that this was not a significant problem.[10] Assuming proportionality between the shifts in ^{1}H NMR signals and the extent of protonation, we estimate that the 3-ethoxycarbonyl dienone is (25 ± 3)% protonated in trifluoroacetic acid, in which the 4,4-dimethyl dienone was estimated to be *ca.* 60% protonated.[10] The rate constant for methyl migration in the cation should thus be four times greater than k_{obs} *i.e.* k_{obs} (2.2 ± 0.2) × 10^{-6} s^{-1} and k_1 *ca.* 8.9 × 10^{-6} s^{-1}. This compares with k_{obs} 1.75 × 10^{-5} s^{-1}, and k_1 2.8 × 10^{-5} s^{-1} for rearrangement of the 4,4-dimethyl dienone in trifluoroacetic acid.[10] The 3-ethoxycarbonyl group would then seem to have effected a reduction in reactivity to about a third of that of the 4,4-dimethyl dienone. However, these comparisons are at slightly different temperatures, and possibly at slightly different acidities, and depend critically on the estimated degree of protonation, so we believe our data based on the results in sulphuric acid to be more reliable. The ^{1}H NMR shifts are important in suggesting that the ester group is not significantly protonated. If it were, the downfield shift of 2-H should be greater than that for 6-H, which is not the case. The degree of protonation calculated from the shifts of 2-H and 6-H (22 and 26%, respectively) agrees well with that based on 5-H (28%). The rearranging cation is therefore formulated as (**4**; R = OEt). The NMR shifts which arise when 3-acetyl-4,4,5-trimethylcyclohexa-2,5-dienone is dissolved in trifluoroacetic acid (0.35 ppm for 2-H and 6-H) suggest that it is *ca.* 35% protonated. The identical shifts for the two protons suggest that the acetyl group is not itself significantly protonated. A less precise estimate can be based on the shifts of the 5-methyl group. Conversion of dienones into their cations moves the ^{1}H NMR signals of 3-or 5-methyl groups downfield by 0.45 ppm.[9] The shift of 0.14 ppm for the 5-methyl group of (**10**) corresponds to *ca.* 30% protonation.

Discussion

The effect of the acyl groups on the rearrangement rates will be discussed using quantitative ideas we have used before. The plot of rate *vs.* acidity for the 3-acetyl dimethyl dienone is of a form identical with those found for other dienones which have been shown to follow the A1 mechanism,[4,5,6,8,11] and is taken as sufficient evidence that the same is true here. That is, the carbonyl-protonated dienone (**4**) is formed in a rapid equilibrium defined by equations (1) and (3). It then rearranges slowly, by a first-order process defined by equations (2) and (4). The measured rate, k_{obs}, depends on the amount of cation present, and on its inherent reactivity at any acidity. In an earlier report[12] we gave equation (5), which correlated the rearrangement rates for the cations of many dienones (**14**) with the Hammett–Brown σ^+ constants of the substituents X. The correlation is for standard conditions,[12] rearrangement in 70% w/w sulphuric acid at 25 °C (H_0 -5.80).[13]

$$\log k_1 = -(3.97 \pm 0.24) - 3.96\,[(\Sigma\sigma^+)_{15} - (\Sigma\sigma^+)_{14}] \quad (5)$$

In order to predict the rates for the cations of the present 3-acyl dienones we need to know the σ^+ values for an acetyl or ethoxycarbonyl group *ortho* to the sp^3 carbon atom (corresponding to the *ortho* position in electrophilic aromatic substitution), and the σ_m^+ values. The *meta* constants are taken as identical with the normal σ_m values established from benzoic acid ionisation *i.e.* 0.38 for acetyl and 0.37 for ethoxycarbonyl.[14] In order to estimate σ_o^+ values for these groups we used the empirical method of Taylor and his co-workers,[15,16] in which σ_o^+ values are given as 0.87 times the σ_p^+ value. This gives the σ_o^+ value for acetyl as 0.44, and for ethoxycarbonyl 0.40. These values depend on there being no significant steric effects in the reactions. The predicted values for $\log (k_1/s^{-1})$ are then (-3.73 ± 0.40) for the acetyl dienone, and (-3.85 ± 0.71) for the ethoxycarbonyl analogue. The experimental values, marginally extrapolated to 70% acid, are *ca.* -3.1 and -3.2, respectively. The predicted value for the 3,4,4-trimethyl dienone is (-4.76 ± 0.24). Equation (5) therefore does predict acceleration by the acyl groups, but only by a factor of 10. The discrepancy may reflect some additional destabilisation of the protonated dienone, such as a steric interaction, which is not reflected in our calculation, or a defect in the σ^+ values.

The acceleration of rearrangement found in the 3-acetyl-4,4-dimethyl dienone is also shown in the 3-acetyl-4,4,5-trimethyl compound. Although this reacts slowly ($k_{obs} = k_1 = 4.8 \times 10^{-7}$ s^{-1} in 68.2% sulphuric acid, half-life *ca.* 400 h, or 17 days) it does react much faster than the 3,4,4,5-tetramethyl compound which showed less than 1% reaction in 20 days ($k_{obs} = k_1 \ll 8 \times 10^{-9}$ s^{-1}), an acceleration of at least 60 times. This can probably be explained in exactly the same way as above. However, the situation is not simple, and is discussed in more detail in the following section.

Rearrangement of 3,4,4,5-*Tetrasubstituted Cyclohexa*-2,5-*dienones.*—In earlier work we gave the rate $k_{obs} = k_1$ for rearrangement of the 3,5-diethyl-4,4-dimethyl dienone as $(1.67 \pm 0.03) \times 10^{-7}$ s^{-1} (in 70% sulphuric acid at 25 °C),[4] and 2.1×10^{-7} s^{-1} for the 3,4,5-trimethyl-4-ethyl dienone in which the ethyl group migrates *ca.* 50 times faster than methyl.[6] We estimated[4] that methyl migration from C-4 to C-5 has k_{obs} = k_1 = *ca.* 1.7×10^{-7} s^{-1}. These rates are very close to that found for the 3-acetyl-4,4,5-trimethyl dienone. Our conclusion before was that although a 4–5-methyl migration is slow, the intermediate (**16**; R = Me) can revert to (**17**; R = Me) faster than further migration occurs from C-5 to C-6,[*] and that for the 3,4,4,5-tetramethyl compound this last is the rate-limiting step. Clearly, the overall rearrangement should be accelerated if the migrating group in (**17**)–(**16**) or (**16**)–(**18**) is a better migrator (*e.g.* ethyl instead of methyl). The 3-acetyl group in (**10**) may thus exert its effect by accelerating the methyl migration from C-4 to C-5, but it could also affect the distribution between migration back to C-4 and forward to C-6. The rate of migration of the 4-methyl group to C-3 is probably controlled by two major factors. The first, which may be seen by comparing the structures of the rearranged cations (**12**) with (**21**), would suggest preferential migration to C-3. The ion (**12**) for 3-migration is stabilised by an *ortho*- and a *meta*-methyl group (sum of σ^+ values, -0.34) whereas (**21**), for migration to C-5, has an *ortho*-methyl and a *meta*-acetyl group (sum of values, $+0.11$), so equation (5) would suggest faster migration to C-3, by a factor of *ca.* 60. However, the use of equation (5) here may be too simplistic, because it ignores steric influences. More importantly, the acetyl group must decrease the positive charge at C-3 in the protonated dienone, which must be critical for the rate of reaction.

Experimental

The cyclohexadienones were analytically pure new compounds, the synthesis of which will be published shortly.[17] Kinetic measurements were made using UV spectrophotometry, as before.[18]

Rearrangement of 3-*Acetyl*-4,4-*dimethylcyclohexa*-2,5-*dienone* (**3**; R = Me).—The dienone (17.1 mg) in 49% aqueous sulphuric acid (2 cm)^3 at 20 °C gave a slow rearrangement. Brown needles deposited within 24 h. After 5 days the mixture was diluted with water, extracted with ether, and the dried extracts evaporated to a quantitative yield of a solid, identified as 3-acetyl-4,5-dimethylphenol, $\delta_H(CDCl_3)$ 2.24 (3 H, s, 4- or 5-Me), 2.25 (3 H, s, 4- or 5-Me), 2.52 (3 H, s, acetyl), 5.47 (1 H, br s, OH), 6.77 (1 H, d, *J* 2.5 Hz, 6-H), and 6.84 (1 H, d, *J* 2.5 Hz, 2-H).

Rearrangement of 3-*Acetyl*-4,4-*dimethylcyclohexa*-2,5-*dienone* (**3**; R = Me) *in Acetic Anhydride.*—The dienone (51.2 mg) in distilled acetic anhydride (3.1 cm^3) and conc. sulphuric acid (1 drop) was stirred at 20 °C for 7 h. The mixture was quenched with water (20 cm^3) and stirred overnight at 20 °C. Extraction with ether, and washing of the extract with aqueous sodium hydrogencarbonate and then brine, drying, and concentration under reduced pressure gave an oil. Column chromatography on silica with dichloromethane removed a trace of an unidentified impurity and gave 3-acetyl-4,4-dimethylphenyl acetate, ν_{max} 1 770, 1 695, 1 210, and 1 195 cm^{-1}; $\delta_H(CDCl_3)$ 2.30 (6 H, s, 4- and 5-Me), 2.31 (3 H, s, acetate), 2.54 (3 H, s, acetyl), 7.00 (1 H, d, *J* 2.3 Hz, 6-H), and 7.11 (1 H, d, *J* 2.3 Hz, 2-H). The lack of symmetry in the spectra of the phenol and its acetate, the small coupling between the two aryl protons, (*meta* to one another), and the chemical shifts, all support the structure assigned [Found: M^+, 206 (7%). Calc. for $C_{12}H_{14}O_3$: *M*, 206]. Major fragments *M* 164, (57%, loss CH_2CO), 149 (100%, further loss Me), and 121 (15%, further loss CO).[†]

Attempted Rearrangement of 3-*Acetyl*-4,4-*dimethylcyclohexa*-2,5-*dienone in Trifluoroacetic Acid.*—The dienone (14.4 mg) in neat trifluoroacetic acid (1.0 cm^3) after 4 days at 20 °C, followed by isolation, gave complete recovery of the unchanged dienone.

---

[*] This slow, reversible process, and the difficulty of further migration to C-6, have been elegantly confirmed in the rearrangements of (**19**; *n* = 2 and 3) to (**20**).[7]

[†] The changes in chemical shift due to acetylation of the phenol agree to within 0.1 ppm with the correlations reported in refs. 19 and 20. The chemical shifts of the aryl protons differ in the expected way from those in 3-acetyl-2,6-dimethylphenol and 3-acetyl-2,5,6-trimethylphenol,[21] in 3,4,5-trimethylphenol (see later), in 2-acetyl-4,5-dimethylphenol and its acetate,[22] and in 2-acetyl-3,5-dimethylphenyl acetate.[23]

Rearrangement of 3-*Acetyl*-4,4,5-*trimethylcyclohexa*-2,5-*dienone* (**10**) *in Sulphuric Acid.*—The dienone (21.8 mg) was kept in 68.2% sulphuric acid at 40 °C during 50 h. After dilution with ice and extraction with ether in the usual way, the evaporated dried extracts gave an orange oil (25 mg). Analysis by GLC (10% silicone gum, 172 °C) showed the presence of unchanged dienone (*ca.* 2 parts), hydrocarbon impurity from the dienone, and a phenolic product (*ca.* 1 part), ν_{max} (CCl_4) 3 400br, 1 680 cm^{-1}, δ_H($CDCl_3$) 2.20 (9 H, s, Me), 2.45 (3 H, s, Me), and 6.50 (1 H, s). Extraction from dichloromethane with sodium hydroxide solution (1.0 mol dm^{-3}), and acidification (dil. HCl), re-extraction, drying, and evaporation, gave the rearrangement product, δ_H($CDCl_3$) 2.09 (small s), 2.21 (s, Me), 2.28 (s, Me), 2.51 (s, acetyl), 6.50 (s, aryl and OH), and 6.82 (s, aryl). Deuterium exchange with D_2O reduced, but did not remove, the peak at δ 6.50. The spectrum matched that of authentic 3,4,5-trimethylphenol, δ_H($CDCl_3$) 2.05 (3 H, s, 4-Me), 2.19 (6 H, s, 3- and 5-Me), 5.38 (1 H, br s, OH), and 6.48 (2 H, s, 2- and 6-H), together with peaks we assign to 3-*acetyl*-4,5,6-*trimethylphenol* at 6.82 (1 H, s, 2-H), 2.51 (3 H, s, acetyl), 2.29 (3 H, s, Me), and 2.21 (6 H, s, 2 × Me). The presence of 3,4,5-trimethylphenol was confirmed by HPLC analysis and comparison with an authentic sample (Spherisorb SPG column, dichloromethane, UV detection at 280 nm). Analysis by GLC/mass spectrometry confirmed this and gave the formula of the acetyl(trimethyl)phenol (Found: M^+, 178.0981. $C_{11}H_{14}O_2$ requires *M*, 178.099). Good peak-matching with 2,4,6-trimethylphenol and 3-acetylphenol,[24] and the chemical shifts support the structure for the rearrangement product. The ratio of 3-acetyl-4,5,6-trimethylphenol to 3,4,5-trimethylphenol was *ca.* 3.1:1.

3-*Acetyl*-4,4,5-*trimethylcyclohexa*-2,5-*dienone* (**10**) *in Trifluoroacetic Acid.*—The dienone was kept in trifluoroacetic acid at 35 °C for 28 days, with monitoring by ^1H NMR spectroscopy. No change was detected. The chemical shifts, δ_H(CF_3CO_2H) 1.52 (6 H, s, 4-Me), 2.22 (3 H, d, *J* 1.5 Hz, 5-Me), 2.60 (3 H, s, acetyl), 6.55 (1 H, m, 6-H), and 7.20 (1 H, d, *J* 1.5 Hz, 2-H) suggest the dienone to be *ca.* 35% protonated in this acid (see the Discussion).

Rearrangements of 3-*Ethoxycarbonyl*-4,4-*dimethyl-cyclohexa*-2,5-*dienone* (**3**; R = OEt).—(*a*) *In sulphuric acid.* The dienone (17.9 mg) was stirred in 68.2% aqueous sulphuric acid (2.0 cm^3) at 25 °C for 2.5 h. Crushed ice was added, the suspension extracted with ether, and the extract worked up in the usual way to give a yellow oil in quantitative yield. Analysis by GLC (silicone gum at 172 °C) showed a trace of unchanged dienone, a small unidentified peak, and the major product, ν_{max}(CCl_4) 3 440 (OH), and 1 720 (C=O) cm^{-1}; δ_H($CDCl_3$) 1.37 (3 H, t, *J* 7 Hz, ester Me), 2.25 (3 H, s, 5-Me), 2.34 (3 H, s, 4-Me), 4.33 (2 H, q, *J* 7 Hz, ester CH_2), 4.96 (1 H, s, OH), 6.80 (1 H, d, *J* 2.7 Hz, 6-H), and 7.13 (1 H, d, *J* 2.7 Hz, 2-H), assigned to 3-*ethoxycarbonyl*-4,5-*dimethylphenol* (**9**; R = OEt) (Found: M^+, 194.0946. $C_{11}H_{14}O_3$ requires *M*, 194.0939). The results of kinetic measurements made under these conditions are given in Table 1.

(*b*) *In trifluoroacetic acid.* The dienone (21.2 mg) in CD_2Cl_2 (0.5 cm^3) in an NMR tube was treated with trifluoroacetic acid (0.4 cm^3) at 35.1 °C, with monitoring by NMR spectroscopy. After 14 days all the dienone had reacted. Work-up gave an oil (15.0 mg) identical with that given above. A similar rearrangement in neat trifluoroacetic acid gave an initial spectrum for partially protonated dienone, with δ_H 1.40 (6 H, s, 4-Me), 1.30 (3 H, t, *J* 7 Hz, ester Me), 4.43 (2 H, q, *J* 7 Hz, ester CH_2), 6.51 (1 H, d, *J* 8 Hz, 6-H), and 7.25 (2 H, m, 2- and 5-H). After 13 days, when no dienone remained, the spectrum was identical with that of 3-ethoxycarbonyl-4,5-dimethylphenol isolated before. These solutions were used to give kinetic data for the rearrangement, as $k_{obs} = (2.23 \pm 0.02) \times 10^{-6}\ s^{-1}$ in neat trifluoroacetic acid at 37 °C. Given the fact that we calculate *ca.* 25% of the dienone to be in the form of its cation, the rate constant for the cation, k_1, is *ca.* $8.9 \times 10^{-6}\ s^{-1}$.

Reaction of 3,5-*Di*(*methoxycarbonyl*)-4,4-*dimethylcyclohexa*-2,5-*dienone with Sulphuric Acid.*—The dienone (9 mg) in 68.2% sulphuric acid was allowed to stand at 25 °C for 7 days. After dilution with ice, extraction with ether, washing, and drying, the extracts were concentrated to an oil shown by ^1H NMR spectroscopy to contain mainly unchanged dienone, with some acid produced by hydrolysis of the ester, and traces of minor products. The rate constant for the loss of dienone UV absorption in 68.2% sulphuric acid at 25.0 °C is $1.25 \times 10^{-7}\ s^{-1}$ (log k_{obs} −6.90).

Acknowledgements

We thank the SERC for a studentship to G. G.

References

1 L. B. Jackson and A. J. Waring, *J. Chem. Soc., Perkin Trans. 1*, 1988, 1791.
2 L. B. Jackson and A. J. Waring, *unpublished work.*
3 A. J. Waring and J. H. Zaidi, *J. Chem. Soc., Perkin Trans. 1*, 1985, 631.
4 K. L. Cook and A. J. Waring, *J. Chem. Soc., Perkin Trans. 2*, 1973, 88.
5 M. J. Hughes and A. J. Waring, *J. Chem. Soc., Perkin Trans. 2*, 1974, 1043.
6 J. W. Pilkington and A. J. Waring, *J. Chem. Soc., Perkin Trans. 2*, 1976, 1349.
7 B. Hagenbruch and S. Hünig, *Chem. Ber.* 1983, **116**, 3884.
8 A. J. Waring, *J. Chem. Soc., Perkin Trans. 2*, 1979, 1029.
9 K. L. Cook, M. J. Hughes, and A. J. Waring, *J. Chem. Soc., Perkin Trans. 2*, 1972, 1506.
10 J. N. Marx, J. C. Argyle, and L. R. Norman, *J. Am. Chem. Soc.*, 1974, **96**, 2121.
11 V. P. Vitullo, *Chem. Commun.*, 1970, 688; V. P. Vitullo and N. Grossman, *J. Am. Chem. Soc.*, 1972, **94**, 3844.
12 A. J. Waring, *Tetrahedron Lett.*, 1975, 171.
13 C. D. Johnson, A. R. Katritzky, and S. A. Shapiro, *J. Am. Chem. Soc.*, 1969, **91**, 6654.
14 J. Shorter, 'Correlation Analysis of Organic Reactivity,' Research Studies Press (a division of Wiley), Chichester, 1982.
15 H. V. Ansell, J. le Guen, and R. Taylor, *Tetrahedron Lett.*, 1973, 13.
16 M. M. J. le Guen and R. Taylor, *J. Chem. Soc., Perkin Trans. 2*, 1976, 559.
17 G. Goodyear and A. J. Waring, to be published.
18 A. J. Waring, *Anal. Chim. Acta*, 1983, **153**, 213.
19 R. J. Highet and P. F. Highet, *J. Org. Chem.*, 1965, **30**, 902.
20 L. P. Lindeman and S. W. Nicksic, *Anal. Chem.*, 1964, **36**, 2414.
21 B. Fohlisch and O. Herrscher, *Tetrahedron*, 1985, **41**, 1979.
22 A. Fischer, C. C. Greig, and R. Roderer, *Can. J. Chem.*, 1975, **53**, 1570.
23 H. Garcia, R. M. Utrilla, and M. A. Miranda, *Liebigs Ann. Chem.*, 1985, 589.
24 Eight Peak Index of Mass Spectra, Mass Spectra Data Centre, AWRE, Reading, UK, vol. 1, 1970.

Paper 9/02933H
Received 11*th July* 1989
Accepted 21*st September* 1989