Acyl Migrations in Diels–Alder Adducts of Acyl-1,4-benzoquinones

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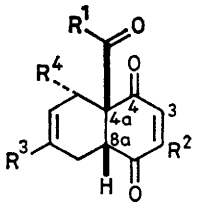
Summary Treatment of several 4a-acyl-4a,5,8,8a-tetrahydro-1,4-naphthoquinones with boiling acetic anhydride gives the 1,4-diacetoxy-2-acyl-5,8-dihydronaphthalenes, and the corresponding 1,4-dihydroxy-compounds are formed when acetic acid is used, but the latter are more readily obtained, *via* the $\Delta^{8a,1}$ enols, by treatment with

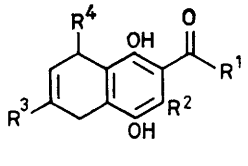
pyridine or pyridine–methanol; these basic reagents cause deformylation of the 4a-formyl analogues, but transfer of the formyl group to the oxygen at C-4 can be effected with imidazole.

WE report herein and in the following two Communications[1] work on the migration of angular substituents in the Diels–Alder adducts of acyl- and benzoyl-1,4-benzoquinones which establishes that the corresponding enols are key intermediates, and confirms and extends independent observations recently reported by Cooper and Sammes.[2]



(1)

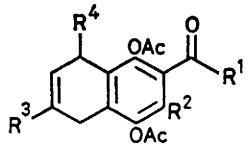
	R^1	R^2	R^3	R^4
a	Me	H	H	H
b	Me	Me	H	H
c	CD_3	H	H	H
d	Me	D	H	H
e	H	H	H	H
f	H	D	H	H
g	Me	H	H	Me
h	Me	Me	H	Me
i	Me	D	H	Me
j	Me	H	Me	H
k	Me	Me	Me	H



(2)

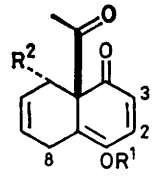
	R^1	R^2	R^3	R^4
a	Me	H	H	H
b	Me	Me	H	H
c	CD_3	H	H	H
d	Me	D	H	H
e	H	H	H	H
f	Me	H	H	Me
g	Me	Me	H	Me
h	Me	D	H	Me
i	Me	H	Me	H
j	Me	Me	Me	H

Treatment of the Diels–Alder adducts (**1a**) and (**1b**),† (obtained from buta-1,3-diene and, respectively, acetyl-1,4-benzoquinone and its 5-methyl homologue) with boiling acetic anhydride gives the 2-acetyl-5,8-dihydronapthalenes (**3a**),[3] identical with materials synthesised by adding buta-1,3-diene to the unsubstituted ethene linkages of, respectively, the quinone (**5**)[4] and 2-acetyl-3-methyl-1,4-benzoquinone, followed by hydrolysis and enolisation with dilute sulphuric acid to give (**2a**) and (**2b**), and then acetylation with acetic anhydride to give (**3a**) and (**3b**). When



(3)

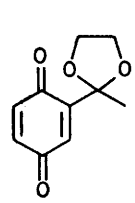
	R^1	R^2	R^3	R^4
a	Me	H	H	H
b	Me	Me	H	H
c	H	H	H	H
d	CD_3	H	H	H
e	H	D	H	H
f	H	H	Me	H



(4)

	R^1	R^2
a	H	H
b	Ac	H
c	D	H
d	Ac	Me
e	H	Me

the adducts (**1a**) and (**1b**) are similarly treated with boiling acetic acid, the corresponding 5,8-dihydro-1,4-dihydroxynaphthalenes (**2a**) and (**2b**) are formed.



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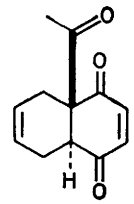

(6)

The 5,8-dihydro-1,4-dihydroxynaphthalene (**2a**) is also obtained when the adduct (**1a**) is heated in propionic acid, and its trideuterio-analogue (**2c**) is formed, without loss of the labelling, when the trideuterioacetyl adduct (**1c**) is treated with boiling protioacetic acid; similar isomerisation of the 2-deuterio-adduct (**1d**) affords the 5,8-dihydro-1,4-dihydroxynaphthalene (**2d**) with > 90% retention of the label.

These results establish that the above isomerisation of the Diels–Alder adduct of buta-1,3-diene and acetyl-1,4-benzoquinone does not involve the retrodiene-recombination route as previously suggested,[5] but that it is intramolecular and occurs with > 90% regioselectivity. The results are consistent[6] with a [1,5] acetyl shift from C-4a to C-3 in the enol (**4a**) or its acetate (**4b**),‡ although the slight loss of deuterium observed with the adduct (**1d**) suggests that an alternative mechanism, in which the acetyl group is transferred to C-2, may compete to a minor extent; evidence relating to this is presented in the following Communication.[1a]

Addition of sodium acetate to the acetic anhydride to facilitate enolisation of the adducts (**1a**) and (**1b**) accelerates the formation of the rearrangement products and slightly increases their yields.

The adduct (**1e**), from formyl-1,4-benzoquinone,[8] behaves similarly when treated with boiling acetic anhydride, giving (**3c**), but only 80% of the deuterium is retained when the deuterio-analogue (**1f**) is used (*cf.* the following Communication[1a]). With acetic acid, the products from (**1e**) are the corresponding isomer (**2e**) and 5,8-dihydro-1,4-dihydroxynaphthalene in the ratio 5 : 9, consistent with the non-enolisable β-keto-aldehyde (**1e**) being more susceptible to cleavage than the β-diketone (**1a**).

Enolisation and subsequent [1,5] acyl shifts can be effected under much milder conditions by using basic media. Thus, when 5—10% solutions of the adduct (**1a**) in pyridine and in pyridine–methanol (1 : 1, v/v) are kept at room temperature for several hours, the isomer (**2a**) can be isolated in high yield. Monitoring of the reaction with ^1H n.m.r. spectroscopy at 35 °C (probe temperature) using [$^2H_5$]pyridine and [$^2H_4$]methanol reveals the build-up and decay of an intermediate, probably the enol (**4c**), because quenching of a parallel solution containing protiomethanol affords a mixture of the rearrangement product, the starting

† The adducts were racemic; only one enantiomer is shown. All the compounds described have analytical and spectroscopic data in accord with the structures assigned to them.

‡ Owing to the much lower migratory aptitude of the methoxycarbonyl group (D. J. Field, D. W. Jones, and G. Kneen, *J. Chem. Soc., Perkin Trans.* 1, 1978, 1050), treatment of the corresponding Diels–Alder adduct from methoxycarbonyl-1,4-benzoquinone and buta-1,3-diene affords the $\Delta^{8a,1}$ enol acetate in > 90% isolated yield (ref. 7).

material, and its *trans*-isomer (**6**).§ A similar [1,5] acetyl shift occurs with the methyl homologue (**1b**), but a temperature of 65 °C is necessary to achieve a preparatively useful rate.

The Diels–Alder adducts (**1g**) and (**1h**), from *trans*-penta-1,3-diene are more easily studied because the 5α-methyl group facilitates enolisation[9] and provides a convenient ^{1}H n.m.r. spectroscopic probe; the doublets (J 7 Hz) due to this methyl group in the adducts (**1**), in their enols, and in the rearrangement products (**2f**) and (**2g**) appear in the δ 1·5—2·5 region for solutions in perdeuteriated pyridine and pyridine–methanol and are usually separated enough to be individually integrated. Thus, for an 8% solution of (**1g**) in [$^2H_5$]pyridine at 35 °C, the proportion of its enol form reaches a maximum of 78% within 1 h and rearrangement to 95% of (**2f**) is complete within 12 h; addition of acetic anhydride after 1 h scavenges the enol as its acetate¶ (**4d**). The enol (**4e**) in [$^2H_5$]pyridine, and its acetate, in [^{2}H]chloroform or [$^2H_6$]benzene, are characterised in the olefinic region of their ^{1}H n.m.r. spectra by a doublet (J 10 Hz) due to 2-H and, at higher field, a doublet of doublets (J_1 10 and J_2 1 Hz) due[1b,7] to 3-H, which is long-range coupled (^6J 1 Hz) to one, probably the β-, of the two protons at C-8. The 2-methyl homologue (**1h**) behaves similarly, but enolisation is slower.

Addition of progressively increasing proportions of [$^2H_4$]methanol to solutions of the adduct (**1g**) in [$^2H_5$]-pyridine accelerates both steps, and, for a 1 : 1 (v/v) solvent mixture, the pseudo-first order rate constant for enolisation is increased by a factor of five, and that for rearrangement of the enol by a factor of ten. Further increases in the proportion of methanol retard enolisation, but continue to accelerate rearrangement, although to a progressively decreasing extent.** The enol was not detected in a solution in [$^2H_4$]methanol alone and at 35 °C the reaction required 70 h to reach completion.

Although addition of methanol to the pyridine would be expected to accelerate enolisation, its role in the rearrangement has yet to be elucidated. Its effect is probably not a consequence of the increase in dielectric constant (pyridine, 12; methanol, 33) because addition of *N*-methylformamide (dielectric constant 182) decreases the rate of rearrangement.

The yield of the rearrangement product (**2f**; OD instead of OH) obtained from these reactions, and of (**2f**) isolated from systems containing protiomethanol, is *ca.* 95%. The remaining product is 5,8-dihydro-1,4-dihydroxy-5-methylnaphthalene resulting from the competitive cleavage of the non-enolisable β-diketone moiety in the original Diels–Alder adduct, a process which is accelerated by the presence of traces of trifluoroacetic acid (*cf.* ref. 1b).

The regiospecificity of the rearrangement is established by isomerisation of the deuterio-compounds (**1d**) and (**1i**) in pyridine, which occurs with almost complete retention of the label, giving (**2d**) and (**2h**), respectively. However, up to 10% of the label is lost when methanol is present and this can be accounted for by a competing [1,2] acetyl shift for which evidence is presented in the following two Communications.[1]

The Diels–Alder adducts (**1g**), (**1i**), (**1j**), and (**1k**) undergo analogous rearrangements. Representative examples are given in the Table.

The corresponding Diels–Alder adducts (**1**; R^1 = H) of formyl-1,4-benzoquinone do not undergo [1,5] formyl shifts in pyridine or pyridine–methanol, because competing deformylation gives the corresponding 5,8-dihydro-1,4-dihydroxynaphthalenes almost exclusively. However, for-

TABLE. Products from [1,5] acyl shifts in the Diels–Alder adducts (**1**).

Method[a]	Product	Isolated yield/%	M.p./°C	δ[b] OH	OH	R^1	R^2	6-Me	8-Me
A	(**3a**)	52	131—132[c]	—	—	2·50	7·37	—	—
A	(**3d**)	74	131—132	—	—	—	7·37	—	—
A′	(**3b**)	77	129·5—130·5	—	—	2·42	2·03	—	—
B	(**2a**)	32	221—222[d]	12·49	9·48	1·88	7·40[e]	—	—
A	(**3c**)	84	145—147	—	—	9·93	7·42	—	—
A	(**3e**)	78	147—149	—	—	9·93	—	—	—
B′	(**2e**)	28	174—177[f]	11·00	6·78	9·75	6·88[g]	—	—
A	(**3f**)	77	143—146	—	—	9·87	7·37	1·80	—
C	(**2a**)	80	222[d]	12·49	9·48	1·88	7·40[e]	—	—
C	(**2d**)	73	218—220	12·31	7·94	2·51	—	—	—
C′	(**2b**)	55	153—153·5	11·10	6·85	2·57	2·38	—	—
C	(**2i**)	84	208—210	12·29	7·92	2·53	7·12	1·81	—
C	(**2f**)	84	151—153[g]	12·44	7·93	2·52	7·11	—	1·22[i]
C′	(**2j**)	70	164—166	10·98	6·88	2·58	2·39	1·80	—
C′	(**2g**)	72	109—111	11·74	4·30	2·60	2·40	—	1·24[i]

[a] A, 4—8% in Ac_2O, 140 °C, 4 h [for (**3a**), 1 h in the presence of 0·5% NaOAc, yield 75%]; A′, As A, but 35 h [for (**3b**), 2 h in the presence of 0·5% NaOAc, yield 72%]; B, 3% in $EtCO_2H$, 141 °C, 1 h; B′, 2% in AcOH, 118 °C, 1 h; C, 3—5% in 1 : 1 pyridine–MeOH, 20 °C, 24 h; C′, As C, but at 65 °C; [b] Compounds (**3**) in $CDCl_3$, (**2**) in $(CD_3)_2CO$ unless otherwise stated; δ 5·5—6·2 (6-H, 7-H), 3·1—3·6 (5-H, 8-H) and 2·2—2·4 (OAc). [c] Lit., ref. 3, 128·5—129 °C. [d] Lit., ref. 2, 173 °C subl. [e] $(CD_3)_2SO$. [f] Decomp. [g] CD_3CN. [h] Lit., ref. 2, 153 °C. [i] d, J 7 Hz.

§ Factors controlling *cis* ⇌ enol ⇌ *trans* equilibria for Diels–Alder adducts of substituted 1,4-benzoquinones have been determined in a separate investigation (ref. 9).

¶ This and related enol acetates undergo both [1,5] and carbon-to-oxygen acetyl shifts when kept. This aspect is being investigated.

** Pseudo-first order rate constants at 35 °C for solutions in [$^2H_5$]pyridine and [$^2H_5$]pyridine–[$^2H_4$]methanol lie in the ranges 1×10^{-5} to 5×10^{-3} s^{-1} for enolisation and 1×10^{-4} to 5×10^{-3} s^{-1} for rearrangement. A detailed analysis will be presented elsewhere.

myl transfer from C-4a to the oxygen at C-4 to give a *ca.* 40% yield of the monoformate occurs when the adducts are allowed to stand at room temperature in benzene containing 20% of pyridine or 0·4% of imidazole.

A noteworthy feature of the [1,5] acetyl shifts outlined above is the relatively low temperature[10] at which they occur, in high yield, in pyridine and in pyridine–methanol, and this suggests that the rearrangement will have considerable synthetical potential. The corresponding formyl migration, which requires boiling acetic anhydride, may be less versatile.

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[1] (a) F. B. H. Ahmad, J. M. Bruce, J. Khalafy, and K. Sabetian, following communication; (b) R. Al-Hamdany, J. M. Bruce, R. T. Pardasani, and I. Watt, accompanying communication, *J. Chem. Soc., Chem. Commun.*, 1981, 171.
[2] S. C. Cooper and P. G. Sammes, *J. Chem. Soc., Chem. Commun.*, 1980, 633.
[3] L. A. Cort and P. A. B. Rodriguez, *J. Chem. Soc. C*, 1967, 949.
[4] J. M. Bruce and R. Al-Hamdany, unpublished work.
[5] J. M. Bruce, 'Benzoquinones and Related Compounds,' in 'Rodd's Chemistry of Carbon Compounds,' ed. S. Coffey, Elsevier, Amsterdam, 1974, vol. IIIB, ch. 8.
[6] J. M. Bruce, supplement to ref. 5, ed. M. F. Ansell, in the press.
[7] M. U. Akpuaka and J. M. Bruce, unpublished work.
[8] J. M. Bruce, F. Heatley, R. G. Ryles, and J. Scrivens, *J. Chem. Soc., Perkin Trans.* 2, 1980, 860.
[9] J. M. Bruce, M. Haghighi, and I. Watt, unpublished work.
[10] *Cf.* D. W. Jones and G. Kneen, *J. Chem. Soc., Perkin Trans.* 1, 1977, 1313; D. J. Field, D. W. Jones, and G. Kneen, *ibid.*, 1978, 1050; R. J. Bushby and D. W. Jones, *J. Chem. Soc., Chem. Commun.*, 1979, 688; D. J. Field and D. W. Jones, *J. Chem. Soc., Perkin Trans.* 1, 1979, 1273.