Addition of nucleophiles to electron-deficient alkenes: structural studies on the incipient reaction and the zwitterionic intermediate

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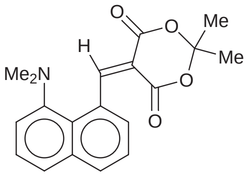
Three distinct interactions between a Me_2N group and an electron-deficient alkene located in the *peri* positions of a naphthalene ring comprise an almost complete cyclisation, an incipient reaction, and a less favourable orientation of the nitrogen lone pair with respect to the alkene, which can be related to the electronic characteristics of the alkene substituents; the cyclised material is zwitterionic and is composed of the enolate of a β-dicarboxylic diester and a trialkylarylammonium cation.

Insight into bond forming and bond breaking processes in chemical reactions have been gained by analysing the geometries of interaction between pairs of functional groups which have been measured by X-ray diffraction.[1] Most notably, a reaction coordinate for the addition of a nucleophile to a carbonyl group was constructed from the structures of a range of molecules in which a tertiary amino group and a carbonyl group were held in close proximity.[2–4] Kirby and Jones studied the spontaneous cleavage of tetrahydropyranyl acetals and glucosides, and were able to show correlations between the length of the exocyclic C–O bond and reactivity.[5–7] Similar studies have been made on the addition of nucleophiles to triple bonds, notably nitriles[8–10] and alkynes.[11–13] The addition of a nucleophile to an electron-deficient carbon–carbon double bond is a very important reaction in organic synthesis. To begin a study of the correlation between the bond formation and bond breaking processes in this type of reaction, we have measured the interactions between a Me_2N group and different electron-deficient alkenes located in the *peri* positions of naphthalenes **1–3** by X-ray crystallography.† The quite distinct molecular structures of these three compounds are presented in Fig. 1, and selected details of their molecular geometries are given in Table 1.



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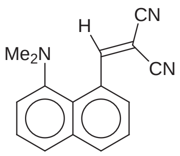

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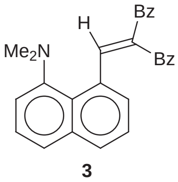

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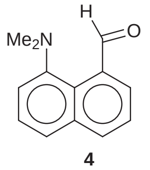

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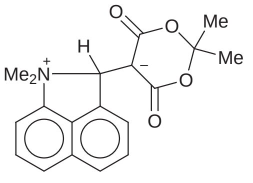

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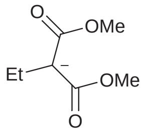

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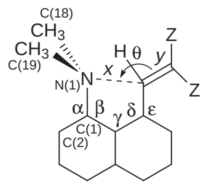
Results for compound **1** show that the nucleophilic addition of the Me_2N group to the alkene is almost complete, and that the structure lies much nearer to the zwitterionic formulation **5** in which a trialkylarylammonium cation and the enolate of a β-dicarboxylic diester coexist. The hexamethylguanidinium salt of the enolate of dimethyl ethylmalonate, **6**, has been reported previously.[14] In the zwitterion **5** the carbon–nitrogen bond [1.651(3) Å] is nearly fully formed, and the π bond of the alkene is almost completely broken [1.471(3) Å, *cf.* 1.510(6) Å in **6**]. The newly formed five-membered ring adopts a half chair conformation with the largest torsion angle [17.1(2)°] about the new N(1)–C(11) bond so that the *N*-methyl groups are displaced by different amounts from the naphthalene plane [C(18), −1.512(3); C(19), 0.860(3) Å].

In contrast, structures **2** and **3** are closer to their uncyclised formulations. However, there is a stronger interaction between the functional groups in **2** than in **3** as indicated by the shorter N(1)···C(11) distance, the lengthening of the alkene bond, and the orientation and in-plane displacement of the Me_2N group into a more favourable position for bond formation with the alkene. Thus, the N(1)···C(11) separations in**2** and **3** [2.413(2) and 2.679(2) Å respectively] are *ca.* 0.8 and 0.5 Å within the sum of the van der Waals radii for these atoms, and the alkene bond is lengthened to 1.354(2) Å in **2** whereas it is only 1.341(2) Å in **3**. Both substituents in **3** are displaced in the plane of the aromatic system in the same sense by *ca.* 2° away from their idealised positions; the Me_2N group is moved towards the other *peri* substituent, which has moved away. In comparison to this, the structure of **2** shows an increase of a further 2° in the displacement of the Me_2N group towards the alkene, but the alkene is displaced by 2° towards the Me_2N group, indicative of a larger attraction between these groups. The larger N(1)···C(11) separation in **3** is partly attained by an increase in the exocyclic

Table 1 Selected molecular geometry for **2**, **3** and **5** presented in order of decreasing attractive interaction between the *peri* groups



	x/Å	y/Å	α (°)	β (°)	γ (°)	δ (°)
5	1.651(3)	1.471(3)	128.6(2)	108.8(2)	113.3(2)	109.9(2)
2	2.413(2)	1.354(2)	124.3(2)	115.9(1)	120.4(1)	120.2(1)
3	2.679(2)	1.341(2)	122.3(2)	118.3(2)	123.5(2)	122.5(2)

	ε (°)	θ (°)	C(18)–N(1)–C(1)–C(2)	C(19)–N(1)–C(1)–C(2)	Naphthalene–alkene angle[a]
5	131.4(2)	114.9(2)	−71.9(2)	49.5(3)	65.5(1)
3	120.3(1)	112.5(1)	−81.5(2)	49.2(2)	64.0(2)
2	117.6(2)	118.0(1)	−105.0(2)	25.9(3)	54.4(1)

[a] Angle between naphthalene system and the plane of the alkene.

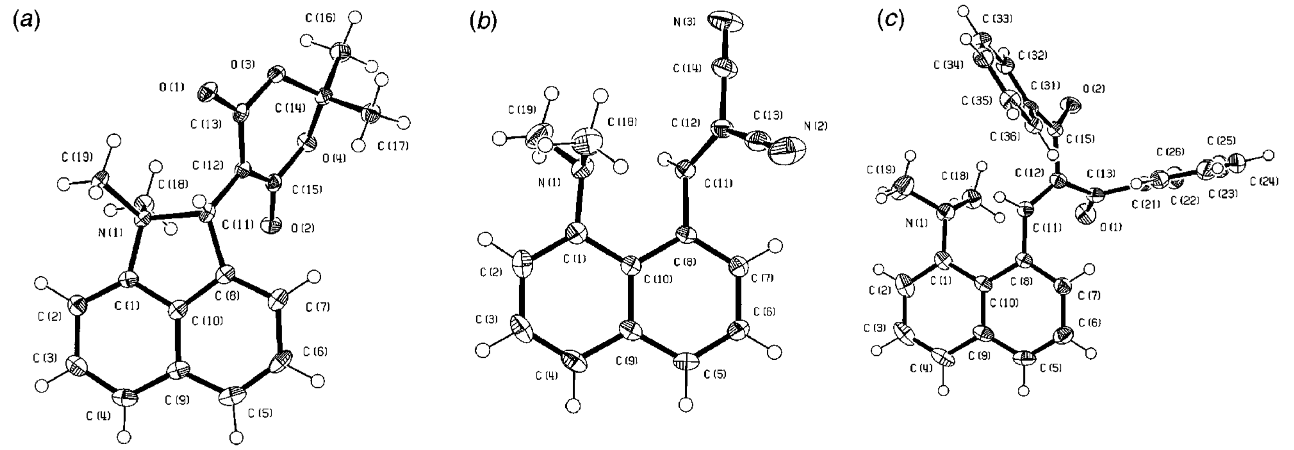


Fig. 1 The structures of molecules (*a*) **5**, (*b*) **2** and (*c*) **3** with atomic displacement parameters drawn at the 50% level.

bond angle at C(10) by *ca*. 3° in the naphthalene system. Furthermore, while the Me_2N group in **3** is oriented such that the axis of its lone pair would lie at 30° to the N(1)···C(11) vector, and thus poorly aligned with the α-C atom of the alkene, in **2** the alignment is considerably better, with the axis of the lone pair lying only 13° away from the N(1)···C(11) vector. Indeed, the orientation of the Me_2N group in **2** is very similar to that in the cyclised material **5**. There is evidence in **2** for a slight pyramidalisation at the alkene's α-C atom, C(11), where this atom deviates from the plane of its three neighbours by 0.087(7) Å towards the amino nitrogen atom. The failure of the nitrogen lone pair to be attracted to the alkene in **3** is due to the reduced conjugation of the carbonyl groups with the double bond. The torsion angles between the carbonyl groups and the alkene bond are 52.2(3) and –146.6(2)°. In **2** the cylindrical π-system of the nitrile groups ensure conjugation with the alkene, and compound **5** has cyclised since the carbonyl groups are held in conjugation with the developing carbanionic centre by the dioxane ring. The degrees of interaction between the *peri* groups in the three compounds studied mirror the pK_as of the methylene derivatives used to prepare them from **4**.[15] In contrast, the intrinsic rate constant for the reaction of secondary amines with benzylidene derivatives containing the same electron-attracting β-substituents as structures **1**–**3** is highest for the dinitrile $PhHC{=}C(CN)_2$.[16]

The structure of zwitterion **5** is particularly interesting. The enolate grouping shows an asymmetric geometry with the $^{-}C(12){-}C(13){=}O(1)$ fragment showing a greater degree of enolate character than the $^{-}C(12){-}C(15){=}O(2)$ moiety as indicated by a longer C=O bond [1.236(2) *cf.* 1.224(2) Å] and shorter C–C bond [1.409(3) *cf.* 1.428(2) Å]. This higher enolate character may be induced by the formation of a particularly short intermolecular hydrogen bond by O(1) with the naphthalene ring hydrogen atom *ortho* to the positively charged ammonium substituent [O(1)···H(2), 2.20(2) Å, O(1)···H(2)–C(2), 164(2)°]. In addition, each carbonyl oxygen atom makes an intramolecular contact with a methyl hydrogen atom and is involved in further intermolecular contacts with hydrogen atoms (O···C range: 2.38–2.53 Å). Similar contacts were observed between enolate **6** and hexamethylguadinium ions (2.31–2.59 Å) although in this case the enolate geometry was symmetrical [$^{-}$C–C: 1.412 and 1.413, C=O, 1.229 and 1.233 Å).

NMR studies on **2, 3** and **5** dissolved in $CDCl_3$ are consistent with **5** retaining its cyclic zwitterionic structure. The chemical shift for the *N*-methyl groups in **5** (δ 3.37) is *ca*. 0.7 ppm downfield of the corresponding resonances in **2** and **3**, and the shift of the methine hydrogen (δ 7.06) is *ca*. 1.6 ppm upfield of those for the alkenyl hydrogens in **2** and **3**. In the ^{13}C NMR spectrum of **5** the ring sp^3 carbon atom resonates at δ 99.1 and the signal from the carbanionic carbon occurs at δ 69.8. Further work to build up a more detailed picture of the reaction coordinate for nucleophilic addition to an alkene is in progress.

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Notes and references

† *Crystal data* for **2**: $C_{16}H_{13}N_3$, M_r = 247.29, monoclinic, a = 13.606(10), b = 9.042(5), c = 11.073(10) Å, β = 103.38(2)°, V = 1325.3 Å^3, Z = 4, $P2_1/a$, D_c = 1.24 g cm^{-3}, μ = 0.08 mm^{-1}, 2677 unique reflections, 2082 with $F > 4\sigma(F)$, R = 0.050, wR = 0.128. For **3**: $C_{28}H_{23}NO_2$, M_r = 405.47, monoclinic, a = 11.2537(4), b = 11.4933(5), c = 16.7819(6) Å, β = 93.884(2)°, V = 2165.6 Å^3, Z = 4, $P2_1/n$, D_c = 1.24 g cm^{-3}, μ = 0.08 mm^{-1}, 5350 unique reflections, 3759 with $F > 4\sigma(F)$, R = 0.057, wR = 0.164. For **5**: $C_{19}H_{19}NO_4$, M_r = 325.35, monoclinic, a = 9.918(3), b = 12.7145(9), c = 12.2801(8) Å, β = 90.99(1)°, V = 1548.3 Å^3, Z = 4, $P2_1/c$, D_c. = 1.40 g cm^{-3}, μ = 0.1 mm^{-1}, 2381 unique reflections, 1724 with $F > 4\sigma(F)$, R = 0.040, wR = 0.095.

X-Ray diffraction data were collected at 150 K using Mo-Kα radiation located and refined with isotropic displacement parameters. CCDC 182/1110. Crystallographic data is available in CIF format from the RSC web site, see: http://www.rsc.org/suppdata/cc/1999/257

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