BASE-CATALYZED DIMERIZATIONS OF ALKYLIDENEMALONONITRILES

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ABSTRACT

The base-catalyzed dimerizations of several alkylidenemalononitriles have been studied, and proton nuclear magnetic resonance (n.m.r.) spectral evidence is presented in support of the suggested cyclic structures of these dimers.

The preparation of α,β -unsaturated dinitriles of the type $R_2C=C(CN)_2$ by basecatalyzed condensation of the corresponding carbonyl compound ($R_2C=O$) with malononitrile has been the subject of investigation from the time of Heuck onwards (1–9). In addition to the expected unsaturated dinitrile, however, a second substance, considered to be a dimer of the dinitrile, has been isolated in several instances (5). The formation of this dimeric product has previously led to confusion about the nature of the monomeric product. For example, cyclohexylidenemalononitrile (5) and isopropylidenemalononitrile (4) were originally reported to be crystalline solids and it was later shown (6) that they are, in fact, liquids.

These crystalline products are obtained in varying yields from the base-catalyzed condensations of both aromatic and aliphatic ketones with malononitrile. The structures of some of them have recently been investigated (7, 8, 9). Thus, Anderson, Bell, and Duncan (7) studied the solid products obtained from the base-catalyzed reactions of malononitrile with several carbonyl compounds including acetone, acetophenone, and benzil. They suggested, largely on the basis of infrared spectral analysis, that the structure of the dimer of isopropylidenemalononitrile was linear (Me₂C=C(CN).C(NH₂)=CH.CMe =-C(CN)₂). Williams later investigated some of the reactions of this dimer and concluded that it was cyclic (see Chart A (Ia)(Ic)). In a recent communication (9) we have suggested that the dimer of cyclohexylidenemalononitrile is likewise cyclic.

We have now investigated the base-catalyzed dimerizations of other alkylidenemalononitriles in an attempt to determine whether or not the formation of *cyclic* dimers can be considered to be a general reaction of these compounds. The proton n.m.r. spectral evidence which we have obtained leaves little doubt that the dimers are cyclic, but they appear to differ from isopropylidenemalononitrile dimer in the location of the carbon-carbon double bond.

The mechanism for cyclic dimer formation proposed for isopropylidenemalononitrile by Williams (8) can be expanded into the general form shown in Chart A. Compounds I in Chart A represent the reaction sequence for isopropylidenemalononitrile itself. Compounds II, III, and IV represent the three other alkylidenemalononitrile systems studied in this work. Our n.m.r. spectrum of the isopropylidenemalononitrile dimer is included in Fig. 1 for comparison with the spectra of the other dimers.

2-Butylidenemalononitrile Dimer (Chart A, $R = CH_3$; R' = H)

The linear form (Chart B, IV (d), IV (e)) of this dimer analogous to that first suggested for isopropylidenemalononitrile by Anderson, Bell, and Duncan (7) would arise from attack of the primary carbanion on a *nitrile* group of the second molecule rather than on

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FIG. 1. (i) Assignments as shown by letters, (ii) relative peak areas circled numbers, (iii) spectra all 20% approximately in CDCl₃, and (iv) TMS internal standard.

the β -carbon atom. The n.m.r. spectrum (Fig. 1 (II)) of the dimeric product in this case suggests that the material is largely in the amino form II (b), the relative areas of the NH₂ absorption at 4.9τ and of the ethylenic hydrogen absorption at 4.1τ being 1.7 and 0.8 respectively. The linear structure can be ruled out since the 8.7τ value for the methyl singlet places it on a saturated carbon. This cannot be accommodated in structures VI (d) or VI (e). The amino form has been assigned structure II (b), with the double bond exocyclic, rather than II (c), since the latter would be inconsistent with the 8.1τ doublet and with the 4.2τ quartet, which are due to the splitting in the CH₃—CH— group.

3-Pentylidenemalononitrile Dimer (Chart A, $R = R' = CH_3$)

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The n.m.r. spectrum (Fig. 1 (III)) of the dimer again suggests that it is largely in the amino form III (b) (relative area of $NH_2 = 2.2$). In the linear form VII (d), VII (e), only one H_3C —C—H group is present, while the spectrum shows *two* hydrogen quartets, which must arise from this kind of grouping. Hence the linear structure can be ruled out. The presence of these two quartets likewise rules out structure III (c).

Cyclohexylidenemalononitrile Dimer (Chart A, $R + R' = -(CH_2)_{3}$ -)

The proton n.m.r. spectrum has been reported and discussed in a recent communication (9). It is shown for comparison in Fig. 1 (IV).

CHART A

RCH₂ .CN RCH_{2.} RCH₂ CN base, R'CH $C \doteq C$ C≡N + monomer RCH2 ќсн ́ CN CN RCH2 ∽ cn ксн₂ ČΝ н + + RCH CN RCH2 CN °C — NH₂ RCI R'CH C = NHRCH2 -CN RCH2 -CN CN RCH2 ŘС́Н₂ ĊN (b) (a) RCH₂ CN RC $C - NH_2$ RCH₂ CN ` CN R'CH₂ (C) R = R' = H 1 III $R = R' = CH_3$ IV $R = R' = -(CH_2)_3$ -11 R = CH3: R' = H CHART B rch₂ RCH _ CN C = Cbase , monomer rch -`cn RCH5 CN H = Ć ÇH₂R C = C -RCH₂ CN $C = \frac{1}{NH}$ - ć 🗕 c RCH2 ` CN RCH : CN - с **__си) С NH

V R = R = H VII R = $R' = CH_3$ VIII R = $R' = -(CH_2)_3$ -VI R = CH₃: R'= H

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(e)

DISCUSSION

ŔĊH₂^C∼CH₂R

(d)

The evidence presented in support of the cyclic form of the dimeric products would appear to be conclusive. This implies that attack of the carbanion on the β -carbon of the ene-nitrile is preferred over attack on the cyano group in all the examples considered. The reasons for the observed product distribution among the three tautomeric forms indicated in Chart A remain to be discussed.

This product distribution may be explained in terms of (a) the steric repulsion of the

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larger alkyl groups in II and III compared to I, and (b) the degree of substitution of the exocyclic double bond in II and III as compared to I.

The *amino* forms of dimers II and III can be written as either II (b), III (b) with the double bonds exocyclic, or as II (c), III (c) with the double bonds endocyclic. The n.m.r. evidence suggests that the (b) form with exocyclic double bonds is preferred here in contrast to the endocyclic structure I (c), favored in the isopropylidene case. It would appear that in II (b) and III (b) R and R' have less steric interaction than would be the case in the corresponding (c) form. It also suggests that the preferred geometric isomer about the RCH==C(ring) double bond is that with the R group *trans* to the ring segment carrying the R'CH-entity. Steric interaction of this kind would not be important where R = R' = H, i.e. in isopropylidenemalononitrile dimer.

The second major difference between dimer I and dimers II and III is in the nature of the substituents on the exocyclic double bond. The presence of a methyl substituent here appears to enhance the stability relative to that of an exocyclic methylene group. Thus, as a consequence of both of these factors, the (b) forms appear to be favored in the butylidene and pentylidene dimers, in contrast to the endocyclic double bond form (c) in isopropylidenemalononitrile dimer.

The apparent absence of *imino* forms II (a) and III (a) in the dimer products again points to the presence of a driving force favoring relief of steric repulsion between R and R', possible with an exocyclic double bond as in II (b) and III (b). The presence of some 40% to 50% of the imino form in isopropylidenenialononitrile dimer (see Fig. 1 and Ref. 8) means that in itself the *imino* form is not significantly less stable than the *amino* form. It appears then that the dominant factors which determine the almost exclusive production of the amino form must be (i) the steric repulsion between R' and R, and (ii) the added stability conferred by a methyl substituent on the exocyclic double bond.

Similar arguments may be applied to the structure of cyclohexylidenemalononitrile (IV). We previously suggested (9) that the structure of this dimer is the mixture IV (a), IV (c). However, there is also the possibility of the existence of form IV (b), analogous to II (b) and III (b), where the compounds were essentially 100% in these forms. Recent thermodynamic studies (10) have shown that the four hexahydronaphthalenes shown below have relative stabilities as indicated;



These studies might suggest that, in the amino form of cyclohexylidenemalononitrile dimer, IV (b) would be thermodynamically favored over IV (c). If the 3.9τ peak (Fig. 1 (IV)) were considered to be due to the hydrogen on the exocyclic double bond in IV (b) then the relative positions of the peaks in the n.m.r. spectrum of the dimer fit structure IV (b), if it is assumed that the material is essentially *all* in the IV (b) form. As previously noted (9), however, the broad and overlapping character of the cyclohexane hydrogen bands make accurate area correlations difficult.

Dimerization Mechanism

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In the examples considered the case of dimerization appears to depend on the availability of a base-extractable β -hydrogen in the monomeric ene-nitrile. Thus, the dimers of isopropylidenemalononitrile, 2-butylidenemalononitrile, and cyclohexylidenemalononitrile are produced rapidly (1-2 hours) by the action of base. It is also noteworthy that

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in 2-butylidenemalononitrile the base attacks the methyl group exclusively rather than the ethyl CH₂. This agrees with the observation (11) that unsymmetrical ketones, such as ethyl methyl ketone, undergo enolization-controlled reactions on the ethyl CH₂ group in acid, and on the methyl group in base. On the other hand, the fourth monomer, 3pentylidenemalononitrile, where the intermediate carbanion will be destabilized by the adjacent CH₃ group, and which is also more sterically hindered, undergoes dimerization much less rapidly. Some investigators (6) have, in fact, reported that they did not obtain any crystalline dimer from this compound. It may be noted in addition that 3-methyl-2butylidenemalononitrile appears to react sluggishly, and we have as yet obtained only small amounts of the crystalline dimer. Presumably the steric effect of the isopropyl group is coming into play to a significant extent.

Of the base-catalyzed condensations considered here either the monomers or mixtures of the precursor ketones and malononitrile appear to give rise to simple cyclic dimers, except in the case of equimolar mixtures of acetone and malononitrile. In this case there is produced a crystalline solid which analyzes $C_{15}H_{14}N_6$ and which is reported (8) to arise from 1,4-addition of malononitrile to tautomer I (*a*). The production of more complex condensation products of this type from base catalyzed condensations of *arylidenemalononitriles*, such as benzalmalononitrile, appears to be common and will be the subject of a later communication.

EXPERIMENTAL

Preparation of Isopropylidenemalononitrile Dimer (7, 8)

Diethylamine (0.2 ml) was added to a solution of malononitrile (5 g, 0.07 mole) in acetone (19.8 g, 0.34 mole) at room temperature. The reaction mixture became very hot, and, on standing overnight, a solid product formed which was recrystallized from 95% ethanol to give needle crystals; m.p. 170–175° (lit. 171–174°). Anal. Calc. for $C_{12}H_{12}N_4$: C, 67.92; H, 5.67; N, 26.40. Found: C, 67.82; H, 6.08; N, 26.33. Mol. wt. Calc.: 212. Found: 204.

Preparation of 2-Butylidenemalononitrile Dimer

Malononitrile (3.3 g, 0.05 mole) was dissolved in 3.6 g (0.05 mole) of ethyl methyl ketone and 0.2 ml of diethylamine was added to the mixture, which rapidly became very hot. The mixture was left at room temperature overnight, and the solid thus produced was recrystallized from 95% ethanol; m.p. 167–169°. Anal. Calc. for $C_{14}H_{16}N_4$: C, 70.01; H, 6.67; N, 23.30. Found: C, 70.14; H, 6.92; N, 23.35. Mol. wt. Calc.; 240. Found: 255.

Preparation of 3-Pentylidenemalononitrile (6)

Malononitrile (26.4 g, 0.4 mole) and diethyl ketone (38 g, 0.44 mole) were dissolved in 50 ml of benzene, and 3.08 g (0.04 mole) of ammonium acetate plus 4.8 g (0.08 mole) of acetic acid were added to the solution. The mixture was refluxed for 40 minutes under a Dean Stark trap, and 7.8 ml of water was collected. It was then cooled, washed with water several times, and distilled under vacuum. Yield, 48.7 g, (90%); b.p. 150°/19 mm (lit. 122–125°/23 mm); $n_D^{20} = 1.4708$ (lit. $n_D^{25} = 1.4692$).

Preparation of 3-Pentylidenemalononitrile Dimer

Several initial attempts at the dimerization using different bases (piperidine, diethylamine, aqueous ammonia, aniline) resulted in the production of black tars. The following method eventually worked. To 3.4 g (0.025 mole) of 3-pentylidenemalononitrile was added 0.2 ml of diethylamine. The mixture did not become hot, but on standing overnight a glass was formed, which, on addition of 95% ethanol, could be crystallized. Recrystallization from 95% ethanol gave needles; m.p. 165–167°. Anal. Calc. for $C_{16}H_{20}N_4$: C, 71.60; H, 7.46; N, 20.85. Found: C, 71.83; H, 7.60; N, 2.70. Mol. wt. Calc.: 268. Found: 253.

Molecular weights were determined osmometrically.

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