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THE STEREOCHEMISTRY OF THE MICHAEL ADDITION*

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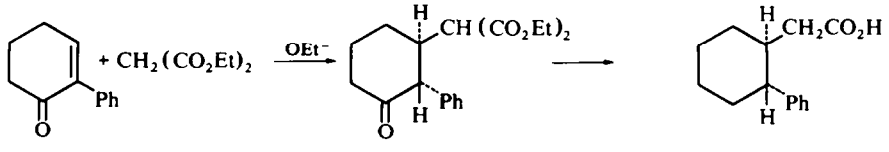
Abstract—The nature of the products obtained in the addition of diethyl malonate to 4-t-butyl-1-cyanocyclohexene under various conditions of solvents, catalysts, and temperature, and their geometries have been determined. In protic solvents, and under conditions of kinetic control, the main product is diethyl *cis*-4-t-butyl-1-cyano-2-cyclohexylmalonate (XII), while under conditions of thermodynamic control the main product is the *trans*-isomer XI. In a non-protic solvent and in the absence of ethoxide ions, the main product is that of an "abnormal" Michael addition, ethyl 4-t-butyl(e)-2-carbethoxymethyl(a)-1-cyano(a)cyclohexanecarboxylate(e) (XXI). It is concluded that in a protic solvent the solvated malonate anion is a relatively weak nucleophile and that product development control operates so that the intermediate with the equatorial malonate residue predominates. Protonation from the least hindered side takes place under kinetic control. In a non-protic solvent the unsolvated malonate anion is a strong nucleophile and the transition states for addition will resemble the ground state. The axial intermediate rearranges rapidly and irreversibly to XXI so that in the absence of a proton donor this product accumulates. No unrearranged axial cyanomalonic ester was ever detected in these reactions. The mechanism of the "abnormal" Michael addition is discussed.

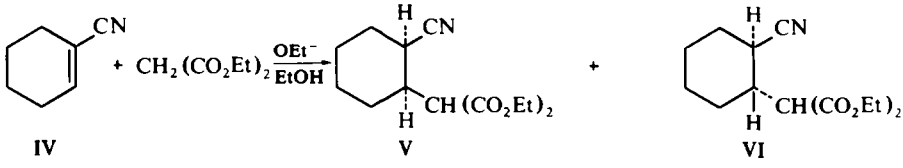
UNTIL this work was initiated very little was known concerning the stereochemistry of the Michael Addition.[1,2] Contradictory results were obtained[3] and in a number of cases, the reaction conditions and the methods of work-up were such as to preclude a decision regarding the mode of addition. For example, the condensation of 2-phenylcyclohex-2-enone (I) and diethyl malonate in the presence of sodium ethoxide and ethanol has been reported to give the *trans*-adduct II which, on acid-catalyzed hydrolysis followed by a Clemmensen reduction, gave the *trans*-acid III.[4,5] It is not clear from this result whether the malonate group added initially to give an intermediate in which the malonate was axial or equatorial. If it added to give the axial intermediate then *cis*-addition of a proton would give the *trans*-diaxial product which would undergo a chair-chair interconversion to the *trans*-diequatorial compound II. Alternatively, *trans* protonation would give a *cis* product initially, which could isomerize in the presence of base to the thermodynamically more stable form (acid-catalyzed isomerization is also possible and could have occurred during the hydrolysis



I II III

* For preliminary Communication see: R. A. Abramovitch and D. L. Struble, *Tetrahedron Letters* 289 (1966).

to III[6]). Similar ambiguities would result if the initial addition gave the equatorial malonate ester. The addition of diethyl malonate to methyl bicyclo[2.2.1]hepta-1,4-diene-1-carboxylate gave the product of *exo-cis* addition.[7] In most of the other cases, it is impossible to determine whether the products formed result from kinetic or from thermodynamic control.[3] Clearly it is difficult to establish with certainty the steric course of nucleophilic addition reactions by studying the conformation of the end products using cyclic systems which may undergo inversion at some stage during the reaction. In the addition of thiols to acetylenic bonds stereospecific *trans*-addition leading to the *cis*-olefin has generally been observed.[8] Other additions, such as that of ammonia to 1-cyclohexenecarboxylic acid[9] or of *p*-toluenethiol to 1-*p*-tolylsulphonylcyclohexene[10] may suffer from the ambiguity discussed above. In an earlier study,[11] it was reported that the addition of diethyl malonate to 1-cyanocyclohexene (IV) in the presence of sodium ethoxide in ethanol gave a mixture of *cis*- (V) and *trans*-diethyl 2-cyanocyclohexylmalonate (VI) in the ratio of 72:28. More accurate gas-chromatographic analysis of this reaction has shown this report to be in error; indeed, under those conditions the ratio of V:VI formed in 30:70. Van Tamelen *et al.*[12] reported that under slightly different conditions only the *trans*-isomer VI is obtained and we have confirmed this observation to the extent that, under the conditions used by these authors, the *cis-trans* ratio is 5:95. Unfortunately, in this



IV V VI

system as well, it is not possible to define with certainty the geometry of the products of kinetic control of the addition, so that after some further work on the effect of solvent and of reaction conditions on this system (see Experimental) it was abandoned in favour of a less ambiguous one.

We have studied the addition of diethyl malonate to 4-t-butyl-1-cyanocyclohexene (VII). The α,β-unsaturated nitrile was prepared from 4-t-butylcyclohexanone *via* the cyanohydrin. When the latter was treated with thionyl chloride at 0–10° di-(4-t-butyl-1-cyano)cyclohexyl sulphite was obtained, but at higher temperatures the dehydration took place smoothly.

The Michael Addition was carried out in ethanol at room temperature under nitrogen for 5 days. In the presence of a half molar equivalent of sodium ethoxide three isomeric products A, B and C were obtained in a total yield of 4·5%, which were resolved by gas chromatography, and their ratio (in the order of their appearance on GLC) determined to be A:B:C = 4:30:66. If only one quarter of a molar equivalent of sodium ethoxide was used only B and C were obtained in the ratio of 5:95. Each had the molecular formula $C_{18}H_{29}NO_4$ expected for the addition product. When the addition was carried out using two molar equivalents of sodium ethoxide in boiling ethanol for 17 hr the main products were again A, B and C, this time in the ratio of 8:81:11, respectively, and in an overall yield of 74%. In addition, small amounts of isomeric acetates were obtained as discussed later. The various compounds could be isolated in the pure state either by preparative gas chromatography

or by fractionation, as described in the Experimental. We shall leave a discussion of the structure of compound A until later and focus our attention on isomers B and C initially.

Compound B, m.p. 86–87·5°, had bands at 2240, 1743 and 1727, and 1365 cm^{-1} in the IR which are characteristic of a cyano group,[13] a malonate ester,[14] and a t-butyl group,[13] respectively. The bands in its NMR spectrum were assigned on the basis of a study of the NMR spectra of a number of authentic malonate esters.[15] The 1H doublet at 6·48 τ (J = 12 c/s) was assigned to the α-proton of the malonate group [$C\underline{H}(CO_2C_2H_5)_2$] and the observed coupling constant suggests that the dihedral angle between this proton and that at C_2 is about 180°.[16] The unsymmetrical broad doublet at 7·12 and 7·35 τ was assigned to the proton β- to the malonate group (C_2—H)[$>C\underline{H}$—$CH(CO_2Et)_2$] and to the proton α- to the nitrile group (C_1—H) ($C\underline{H}CN$),* with the latter probably being the one to contribute to the lower intensity peak at 7·35 τ.† At 100 mc/s each peak of the methylene quartet ($CO_2C\underline{H}_2CH_3$) at 5·82 τ was resolved into triplets (J = 1–2 c/s), [non-equivalent protons due to restricted rotation[19]]. A similar magnetic non-equivalence was observed[20] for the methylene protons of the ethyl ester group in 10-carbethoxy-1,1-dimethyl-*trans*-decalin.

Compound C, m.p. 71·5°, also exhibited the expected infrared bands. The lines in the NMR spectrum were assigned as follows: 4H quartet at 5·78 τ (J = 7 c/s) due to $CO_2C\underline{H}_2CH_3$; 1H doublet at 6·43 τ (J = 11 c/s)[$C\underline{H}(CO_2Et)_2$]; 2H very broad multiplet at 7·19 τ [$C\underline{H}CN$ and $>C\underline{H}CH(CO_2Et)_2$]. Because of the complexity of the multiplet at 7·19 τ the configuration of the C_1—H and C_2—H protons could not be established.

The presence of an unchanged malonate residue in these compounds was confirmed by chemical means. This was done for isomers B and C as illustrated as follows with compound B: (i) treatment of B with sodium ethoxide followed by deuterium oxide[14] gave the α-deuterated malonic ester in which the doublet at 6·48 τ was not present; also the unsymmetrical doublet at 7·12 and 7·35 τ was more symmetrical and narrower in the deuterated compound and appeared at 7·12 and 7·25 τ. (ii) Methylation of B with sodium ethoxide and methyl iodide gave a monomethylated derivative, as expected for a monosubstituted malonate ester, whose IR and NMR spectra were in accord with a cyanomalonate structure.

$$>CD(CO_2Et)_2 \xleftarrow[\text{(ii) } D_2O]{\text{(i) } OEt^-} -CH(CO_2Et)_2 \xrightarrow[\text{(ii) MeI}]{\text{(i) } OEt^-} -\overset{\displaystyle Me}{\underset{\displaystyle |}{C}}(CO_2Et)_2$$

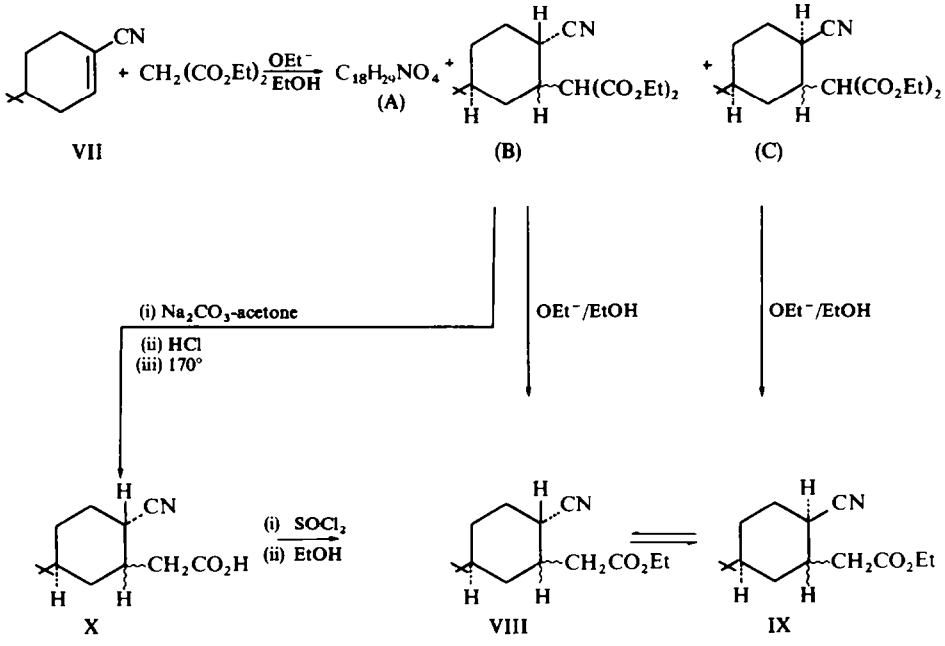
Equilibration of cyanamalonates B and C under conditions similar to those used in the addition gave rise to the three isomers, A, B, and C, as well as to small amounts (23%) of the acetates corresponding to malonates B and C, and to some 4-t-butyl-1-

* The proton α- to the nitrile group in isopropylcyanide absorbs at 7·28 τ.[18]

† As it turns out that this proton is axial and that the compound C with the C–H proton equatorial does not give rise to any definite peak above the very broad multiplet at 7·19 τ it is felt that it is this proton which contributes to the 7·35 τ peak since equatorial protons are known to be less shielded than the corresponding axial ones.[18]

cyanocyclohexene due to the reversal of the Michael addition. Starting from pure B, the ratio of isomers was A:B:C = 11·1:78·5:10·4, while starting from pure C the ratio A:B:C was 4:86·8:9·2. Thus, both the addition reactions carried out at room temperature and in boiling ethanol as well as the above equilibrations indicate that cyanomalonates B and C are epimeric and the $\rangle\underline{C}_1HCN$ carbon atom and that isomer B is the thermodynamically more stable isomer. It has been reported[21] that an equatorial nitrile group is more stable than an axial one ($-\Delta G^\circ$ = 0·15 kcal/mole), which suggested that the nitrile group was equatorial in B and axial in C. This was confirmed as follows.

The acetates derived from isomers B and C which were observed in the above equilibration reactions were also formed in low yield (4%) in the addition of diethyl malonate to VII with sodium ethoxide in boiling ethanol and were in the ratio of 62:38, respectively. These acetates could be obtained *stereospecifically* from the individual pure cyanomalonates by decarbethoxylation with ethanolic sodium ethoxide at room temperature, and were shown by gas chromatography to be uncontaminated with the isomeric acetate. Equilibration of each of VIII and IX showed the acetate derived from B to the thermodynamically more stable than that from C (VIII:IX = 66:34). Acetate VIII could also be obtained more classically from B by

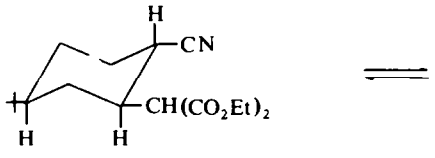


selective hydrolysis of the ester group with sodium carbonate in acetone, decarboxylation of the malonic acid, followed by esterification of the cyanoacetic acid (X) *via* the acid chloride. The NMR spectrum of VIII had a broad 1H singlet at 7·21 τ and a 1H multiplet overlapping this singlet at 7·6 τ, these being due to the $\rangle\underline{C}H\underline{C}N$ and

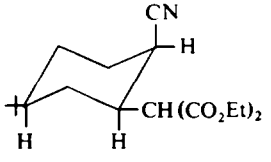
$\rangle$CHCH$_2$CO$_2$Et protons. Unfortunately, due to the complexity of the absorption at 7·6 τ no conclusion could be drawn about the stereochemistry from the spectrum of this isomer.

It has been reported[22] that the ratio $\varepsilon_{eq\ C\equiv N}/\varepsilon_{ax\ C\equiv N}$ for equatorial and axial nitrile groups in fused ring systems ranged from 1·35 to 1·8, provided that the structural environments surrounding the nitrile groups were almost equal in each configuration. The ratio $\varepsilon_B/\varepsilon_C$ was found to be 1·12 for cyanomalonates B and C which, though lower than the above range, is in the right direction if B has an equatorial cyano group and C an axial one.

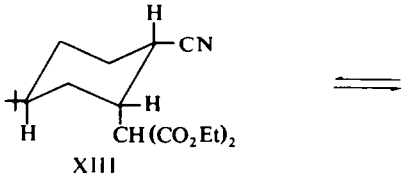
The conformation of the malonate residue, which must be the same in B and C remained to be determined. The possibilities were that B and C were either XI and XII, respectively, or XIII and XIV. A decision between these alternate conformations could be made on the basis of the dipole moments of cyanomalonates B and C. The



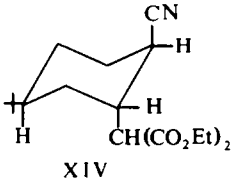
XI



XII



XIII



XIV

dipole moments for XI–XIV can be calculated by taking the values of the bond moments of the nitrile group as 3·56 D[23] and of the diethyl malonate group as 2·10 D[24] assuming that the moment vector for the latter is along the equatorial or the axial direction (and, therefore, that the dihedral angles between these functional group moments is either 60° or 180°) and that the t-butyl group makes no contribution to the dipole moment of those molecules.* The moment thus calculated for XI, XII, and XIII is 4·96 D, while that for XIV is 1·47 D. The moment actually found for B and C was 4·95 and 4·17 D, respectively, so that B must have structure XI and C must be XII.†

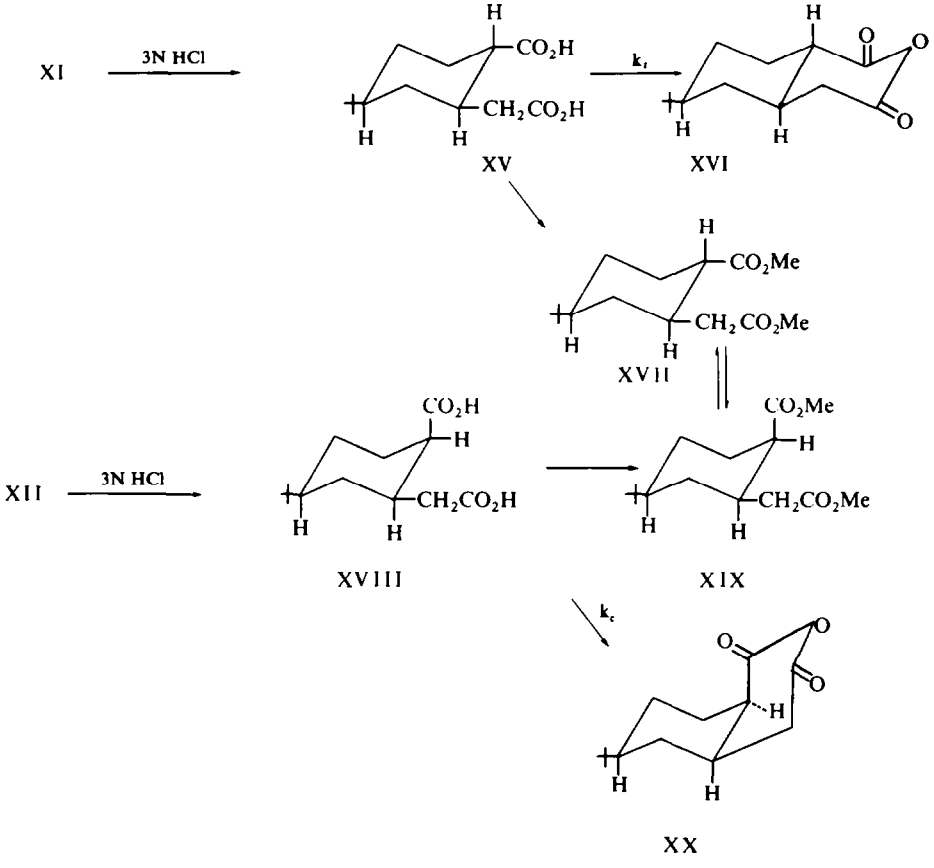
* This assumption is based on the fact that the calculated dipole moments of the equatorial and axial 2-bromocyclohexanones were in good agreement with the values found experimentally for *cis*- and *trans*-2-bromo-4-*t*-butylcyclohexanones.

† The low value (4·17 D) of the moment found for XII may have its origin in one or more of a number of factors. The cyclohexane ring may not be a perfect chair[26] but could be somewhat flattened. Also, different rotational conformers of the malonate group[19] may be involved which could decrease the actual bond moment of this group. The cyano group may be in a thermally excited state during the dipole moment determination, this state being produced by the absorption of energy in the visible region of the spectrum.[27] Bishop *et al.*[28] obtained a similarly low value compared with those calculated for the dipole moment of 3-α-cyanotropane and have suggested that this is due to repulsion between hydrogens on the bridge atoms and the axial cyano group which would lead to a distortion of the conformation of the ring as well as to the possibility that the total moment for cyanocyclohexane may not be exactly along the —C≡N vector.

Chemical confirmation of the equatorial configuration of the malonate residue in B and C was obtained as outlined in Scheme I.

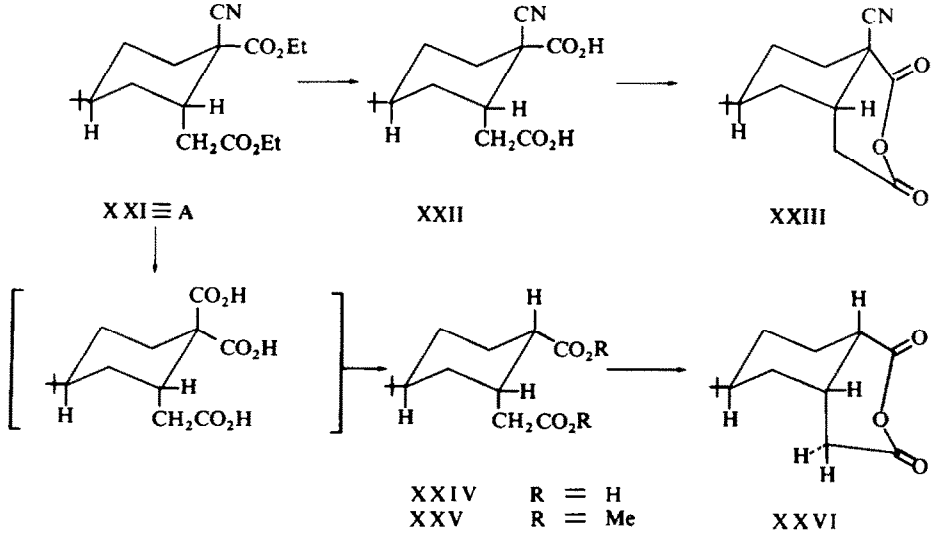
trans-Cyanomalonate (XI) was hydrolyzed stereospecifically to the *trans*-dicarboxylic acid (XV) with boiling 3N HCl. When concentrated hydrochloric acid was used a mixture of *cis*- and *trans*-acids was obtained as expected.[6] Treatment of XV with diazomethane gave the *trans*-diester XVI. Similarly, *cis*-cyanomalonate (XII) gave the *cis*-dicarboxylic acid (XVIII), and thence the *cis*-diester XIX. Equilibration of the dicarboxylic esters could be achieved by heating them with 10% palladium on charcoal at 240°. As expected, the *trans*-ester was thermodynamically more stable than the *cis*, the *cis-trans* ratio at equilibrium at 240° being 17:83, which corresponds to $\Delta G_{CO_2CH_3} = -1{\cdot}6$ kcal/mole. The value reported[29] for $\Delta G^\circ_{CO_2CH_3} = -1{\cdot}1$ kcal/mole. Equilibration of the dicarboxylic acids themselves has been achieved but presents a much more complex picture of free energy differences which will be discussed elsewhere.[30] This equilibration of the esters provided further confirmation of the accuracy of the configurational assignment at C_1 in XI and XII. Both acids formed anhydrides readily. In fact, a rough estimate of the relative rates of formation showed that XX was formed from the *cis*-acid about twice as fast as XVI was formed from the *trans*-acid. i.e. $k_c \simeq 2k_t$. This would definitely not have been expected had the dicarboxylic acid from compound C been the diaxial conformer derived from XIV.

SCHEME I



in which case anhydride formation would have required the cyclohexane ring to go into a twist-boat conformation. Also, the first and second ionization constants of the dicarboxylic acids were determined: for XV $pK_1 = 6{\cdot}45$, $pK_2 = 7{\cdot}22$, $\Delta pK_a = 0{\cdot}77$; for XVIII $pK_1 = 6{\cdot}32$, $pK_2 = 7{\cdot}19$, $\Delta pK_a = 0{\cdot}87$. For *cis*-cyclohexane-1,2-dicarboxylic acid $\Delta pK_a = 2{\cdot}42$, whereas for the *trans*-isomer, $\Delta pK_a = 1{\cdot}75$.[31] In general, this difference is greater the closer together the carboxyl groups are: the *trans*-isomer exists partly in the diaxial form.[32] Thus, had the malonate group in the adducts B and C been axial, the dicarboxylic acid from XIV should have had a much lower ΔpK_a than that from XIII. The observed ΔpK_a values are, however, very close to each other, supporting the proposed equatorial orientation of the malonate residue in the addition products.

Let us now turn to the third isomer, compound A, m.p. 50–52°, obtained in minor amounts from the addition of diethyl malonate to VII in ethanol in the presence of sodium ethoxide. *This compound was the main product when diethyl sodiomalonate (free of ethoxide ions and ethanol) was added to 4-t-butyl-1-cyanocyclohexane in boiling toluene*; the ratio of A : B : C was 91 : 6 : 3. A is not a malonate ester. The nitrile absorption at 2250 cm^{-1}, was a very weak one, suggesting the proximity of an oxygenated function to this group.[33] The NMR spectrum at 100 mc/s was very informative. The doublet at ca. 6·45 τ due to the malonate α-proton was not present with this molecule. Instead of a quartet, the ester methylene protons ($CO_2C\underline{H}_2Me$) gave rise to a 4H 1:3:4:4:3:1 sextet which arose from the superposition of two 1·3:3:1 quartets at 5·72 and 5·89 τ (J = 7 c/s), clearly indicating the presence of two —CO_2Et groups in different magnetic environments. This was accompanied by two resolved triplets at 8·65 and 8·75 τ (J = 7 c/s) due to two different —CO_2CH_2—$C\underline{H}_3$ groups. A three proton singlet was present at 7·7 τ (—$C\underline{H}_2CO_2$Et and C_2—H having the same chemical shift). Treatment of compound A with sodium ethoxide followed by deuterium oxide or by methyl iodide gave only unchanged A. Hydrolysis with 10% aqueous sodium carbonate gave a *stable* cyanodicarboxylic acid XXII which did not decarboxylate readily but formed an anhydride XXIII with ease. Unlike cyanomalonates XI and XII, A did not give a pure compound on attempted hydrolysis with 3N HCl.

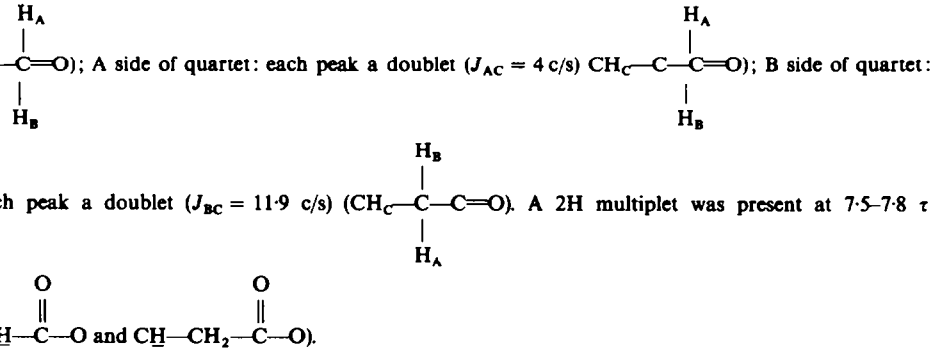


On the other hand, when it was boiled with concentrated hydrochloric acid, both the ester and the cyano group were hydrolyzed, decarboxylation occurred and the product was a dicarboxylic acid XXIV, whose dimethyl ester XXV was different from XVII and XIX. The acetic acid group must, therefore, have the axial orientation in XXV. The new dicarboxylic acid formed an anhydride XXVI readily.* These results and the NMR spectrum are uniquely accounted for by structure XXI for compound A, which is thus a product of the so-called "abnormal" Michael addition.[1] As expected on this basis, the rates of anhydride formation from both XXII and XXIV were about the same and about equal to the rate of anhydride formation from XVIII. The ease with which an anhydride was formed from XXII showed that the C_1 carboxyl group had to be equatorial and the CN axial, rather than the other way around.

DISCUSSION

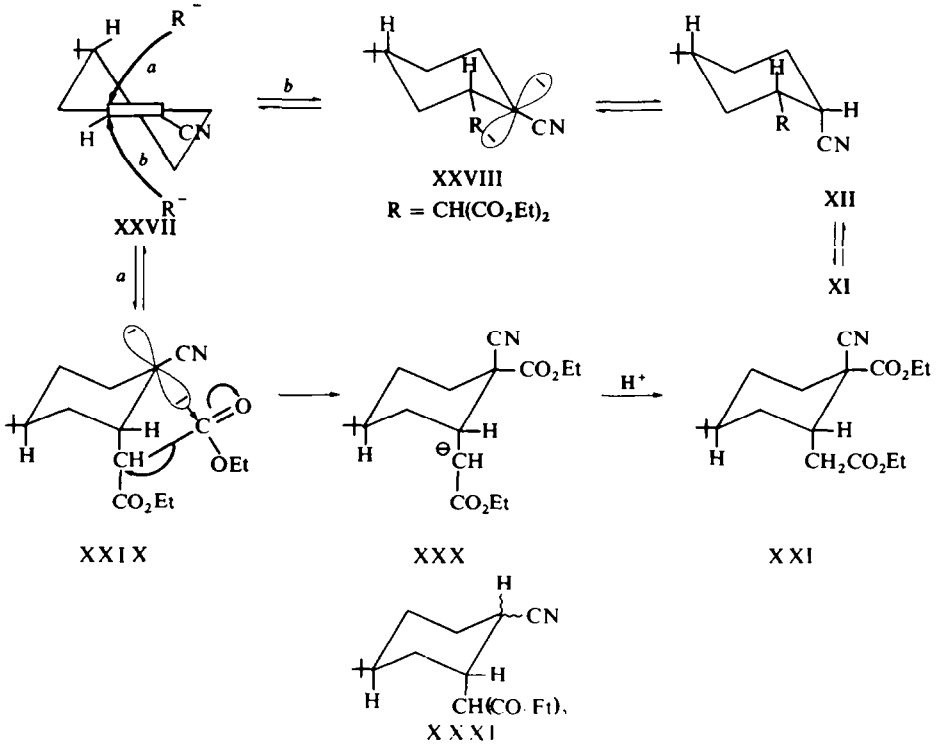
The ratios of products formed from the addition of diethyl malonate to VII under various conditions are summarized in Table 1. The stereospecific decarboxylations observed in the presence of ethoxide ion probably take place by the mechanism proposed by Cope and McElvain.[3,4] Equilibration of *trans*-cyanomalonate (XI) as described previously confirmed the reversibility of this Michael addition and that XI was thermodynamically more stable than the *cis*-isomer XII. Since the addition in ethanol at room temperature gives mainly the thermodynamically less stable product XII it must be the product of kinetic control. The preferential equatorial orientation of the malonate residue may be accounted for as follows. Initial approach of the malonate anion to the olefin in the half-chair conformation XXVII will be in a direction perpendicular to the plane of the double bond for maximum overlap with the π-orbital. Models indicate that there is only a very slight steric preference for approach from the same side as the t-butyl group (to give the equatorial isomer) over approach from the other side. We propose that in ethanol solution the malonate carbanion is highly solvated and is, consequently, a *relatively* weak nucleophile, so that the transition state leading to the intermediate anion formed in the addition will resemble this intermediate rather than the olefin (Hammond postulate[3,5]). As the new bond is formed at C_2 gradual rehybridization occurs, the transition states

* The NMR spectrum of anhydride XXVI exhibited an AB quartet at τ_A 7·18 and τ_B 7·6 (J_{AB} = 17 c/s) due to the non-equivalent protons of the axial methylene group at C_2 adjacent to the carbonyl group



tending towards the chair conformations XXVIII and XXIX.* The transition state leading to the equatorial intermediate XXVIII will consequently be of lower energy than that leading to XXIX and this pathway will be followed ("product development control"). Protonation of XXVIII would then take place from the least hindered side [37], † to give the thermodynamically less stable axial nitrile under kinetic control. The product of thermodynamic control in protic solvents is the *trans*-diequatorial cyanomalonate XI.

No axial malonate ester XXXI was ever detected in this study. This can be rationalized by assuming that migration of a carbethoxyl group from the malonate residue to C_1 is much faster than protonation of XXIX or than internal proton migration from the acidic α-methylene group to C_1. Drieding models indicate that such a migration should be stereochemically blessed from the axial conformation but not from the equatorial one. In addition, migration from the axial group in XXIX would alleviate the 1,3-diaxial repulsions present with the large malonate residue. Assuming that protonation of XXVIII is rapid the amount of XXI formed in ethanol solution is a measure of the extent of attack *via* path *a*. One would expect that the sterically



* Some authors,[36] have suggested that the transition state for approach from the same side as the t-Bu group in similar reactions will exist in a twist-boat conformation with the attacking group pseudo-axial. There seems to be little reason to assume that rehybridization at C_2 will take place in this manner in the present instance rather than to give the chair conformation with the attacking group equatorial, particularly since the 1,3-non-bonded diaxial interactions with the large axial malonate residue would probably greatly overshadow the much smaller developing eclipsing interaction between the malonate residue approaching the equatorial configuration and the cyano group attached to the sp^2 hybridized carbon.

† Ring inversions as discussed[38] cannot occur here.

TABLE 1. ADDITION OF DIETHYL MALONATE TO 4-t-BUTYL-1-CYANOCYCLOHEXENE (VII)

Reaction	Molar ratios of				Solvent	Temp	Time (hr)	Ratio of isomers			Yield %	Ratio of cyano-acetates		Yield %
	Catalyst		Diethyl malonate	VII				XXI	XI	XII		VIII	IX	
	Potassium	Sodium												
1	—	0·5 (3·84 g)	1 (58·4 g)	1 (50·0 g)	EtOH (350 ml)	Room Temp.	120	4	30	66	4·5	—	—	—
2	—	0·25 (0·034 g)	1 (0·96 g)	1 (1·0 g)	EtOH (10 ml)	Room Temp.	120	—	5	95	*	—	—	—
3	—	2 (7·5 g)	3 (75·0 g)	1 (27·0 g)	EtOH (210 ml)	Reflux	17	8	81	11	74·0	62	38	4
4	—	1 (0·126 g)	1 (0·96 g)	2 (2·0 g)	EtOH (11 ml)	Reflux	24	6	90	4	*	58	32	*
5	—	1 (0·126 g)	1 (0·96 g)	1 (1·0 g)	EtOH (11 ml)	Reflux	28	18	72	10	*	64	36	*
6	1 (0·182 g)	—	7 (3·0 g)	1 (0·5 g)	EtOH (22 ml)	Reflux	24	1	82	17	40·0	73	27	4
7	—	1 (5·04 g)	1 (3·94 g)	13 (50·0 g)	Toluene (380 ml)	Reflux	48	91	6	3	17·4	—	—	—
8	—	2 (0·30 g)	3 (3·12 g)	1 (1·06 g)	Toluene (15 ml)	Reflux	24	60	30	10	*	—	—	—
9	—	1 (0·126 g)	1 (0·96 g)	2 (2·0 g)	Toluene (15 ml)	Reflux	24	86	11	3	*	—	—	—
10	—	1 (0·126 g)	1 (0·96 g)	1 (1·0 g)	Toluene (15 ml)	Reflux	28	81	14	5	*	—	—	—

11	2 (0·22 g)	—	6 (3·0 g)	1 (0·5 g)	Toluene (8 ml)	97°	24	51	14	35	8·0	—	—	—
12	—	2 (6·0 g)	3 (62·4 g)	1 (21·0 g)	Dioxan (100 ml)	Reflux	22	66	22	12	54·5	69	31	1
13	2 (0·22 g)	—	6 (3·0 g)	1 (0·5 g)	Dioxan (8 ml)	97°	24	39	22	39	22·0	—	—	—
14	—	1 (0·126 g)	1 (0·96 g)	1 (1·0 g)	DMSO (15 ml)	90°	18	71	17	12	*	—	—	—
15	—	3 (0·184 g)	3 (1·5 g)	1 (0·5 g)	THF (11 ml)	Reflux	17	53	12	35	5·0	—	—	—
16	—	1 (0·126 g)	3 (3·0 g)	1 (1·0 g)	None	97°	24	15	53	32	40·0	—	—	—
17	1 (0·11 g)	—	1 (0·48 g)	1 (0·5 g)	t-Butanol (4 ml)	Reflux	6	—	50	50	*	tr†	tr†	—
18	Amberlite IR 400 (1·0 g)		(1·5 g)	(1·0 g)	Toluene (5 ml)	Reflux	20	—	—	—	—	—	—	—
19	(1·0 g)		(1·5 g)	(1·0 g)	EtOH (10 ml)	Reflux	20	—	—	—	—	—	—	—
20	Amberlite IR 410 (4·0 g)		(1·5 g)	(1·0 g)	Toluene (5 ml)	Reflux	20	—	—	—	—	—	—	—
21	(4·0 g)		(1·5 g)	(1·0 g)	EtOH (10 ml)	Reflux	20	—	—	—	—	—	—	—

* Not determined.

† Trace.

favoured rotamer of the axial malonate group in intermediate XXIX would be that in which the α-proton of the malonate residue was oriented towards the axial ring protons and the carbethoxyl groups pointed away from the ring. In this configuration one of the carbethoxyl groups is in the position desirable for the formation of the 4-centred planar transition state leading to carbethoxyl migration. For the acidic proton to migrate it would have required the malonate group to assume a very unfavourable rotational conformation, with one of the carbethoxyl groups pointing into the ring.

In non-protic solvents, and in the absence of ethoxide ion, the main product formed was, eventually, the cyanodicarboxylic ester XXI (e.g. reaction 7, Table 1). In such solvents, the malonate anion is not externally solvated* and is, consequently, a strong nucleophile. One would then expect the transition states leading to intermediates XXVIII and XXIX to resemble more the ground state with the nucleophile almost perpendicular to the plane of the C=C bond, and the formation of XXVIII in slightly greater amounts than XXIX. In the presence of a proton donor to stabilize the intermediate anion cyanomalonates XI and XII should then be produced more readily than cyanodicarboxylic ester (XXI). In the absence of a proton donor, XXIX can undergo *irreversible* stabilization by carbethoxyl migration to XXX so that, eventually, formation of the latter intermediate is the main product-forming route: XXVIII cannot be stabilized by protonation and reversal of *b* restores the equilibrium XXVIII ⇆ XXVII ⇆ XXIX disturbed by the irreversible transformation XXIX → XXX. An excess of diethyl malonate itself may act as a suitable proton-donor as well. This mechanism is supported by a study of the variation of the ratio of XI, XII and XXI with time in the addition of diethyl malonate to VII in boiling toluene, with or without small amounts of ethanol as a proton donor other than diethyl malonate. Aliquots of the reaction mixtures were removed at various intervals of time and analyzed by gas-chromatography. The results are summarized in Table 2. In the absence of a proton donor the equilibrium lies well on the side of the reactants (Reaction 22, Table 2) and the yields are low. Under these conditions, XXI is the predominant product, as expected from the above considerations. When excess diethyl malonate is the proton donor—not a very efficient one—initially more of the combined (XI + XII) is formed than of rearranged product (XXI); but as the reaction proceeds, more XXI accumulates and eventually predominates to a small extent. Ethanol is a much better proton donor, as can be seen from the results of reaction 24, Table 2. In the latter case, partial solvation of the malonate anion may also be occurring.

The "abnormal" Michael addition encountered here provides, we believe, the first clear cut support of a non-isotropic nature for a Holden–Lapworth type mechanism for this rearrangement.[1] Previous attempts to effect migration of the ester function to a carbon atom bearing a substituent other than an ester group were not successful.[1] The present work establishes unambiguously that the malonate ester group does migrate and the steric course of this migration suggests the intervention of a concerted process *via* a 4-membered transition state (arrows in XXIX). It is unnecessary to postulate a 4-membered *intermediate*, as had already been appreciated.[1] Contrary to another mechanism proposed for the "abnormal" addition[39] the inter-

* Ion aggregates may well be present in such media.

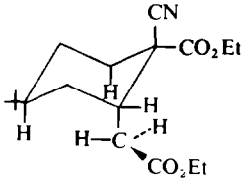
TABLE 2. VARIATION OF ISOMER RATIOS WITH TIME IN THE ADDITION OF DIETHYL MALONATE TO 4-t-BUTYL-1-CYANOCYCLOHEXENE (VII)

Reaction	Molar ratios of			Solvent	Time (hr)	Molar ratios of			Total yield %
	Sodium	Diethyl malonate	VII			XXI	XI	XII	
22	3	3	1	Toluene	1	(0·04 mg)	—	—	0·3
	(0·756 g)	(5·76 g)	(2·0 g)	(90 ml)	3	(0·08 mg)	—	—	0·4
					9	(0·30 mg)	(0·05 mg)	—	1·4
					21	78·6	18·6	2·8	2·8
					30	80·8	16·7	2·5	3·6
					46	82·0	16·1	1·9	4·6
					72	82·8	15·8	1·4	5·0
23	1	2	1	Toluene	1	43·9	43·2	12·9	0·95
	(1·26 g)	(20·0 g)	(10·0 g)	(135 ml)	3·5	52·0	39·6	8·4	2·4
					7	56·0	37·0	7·0	5·4
					19	56·4	36·4	7·2	11·7
					32	57·0	35·5	7·5	15·1
24	1	2	1	Toluene	1	9·2	56·4	34·4	2·7
	(1·26 g)	(20·0 g)	(10·0 g)	(135 ml)	3	11·4	56·2	32·4	7·5
				Ethanol	8	19·0	49·4	31·6	14·7
				(1·5 ml)	21	28·9	46·7	24·4	29·6
					32	34·8	41·8	23·4	34·5
					46	38·2	39·5	22·3	45·2
					96	40·1	38·8	21·1	53·8
25	1	1	1	Dimethyl sulphoxide	24 (at 22°)	—	—	—	—
	(0·378 g)	(2·88 g)	(3·0 g)	(60 ml)	12 (at 35°)	33	17	50	N.D.
					5 (at 70°)	41	28	31	
					20 (at 70°)	78	18	4	

vention of ethoxide ion as an addendum is not required here since the above rearrangement takes place in its absence in a non-protic solvent.*

In some of the additions (reactions 11 and 13) in which potassium rather than sodium was used more of the less stable cyanomalonate XII was observed than of the stable isomer XI; this may be due to incomplete equilibration of the cyanomalonates at the lower temperature used in these reactions. A similar result was obtained when sodium and tetrahydrofuran were used (reaction 15, Table 1). Basic ion-exchange resins have been used as catalysts in a number of Michael additions,[40] but were found to be ineffective with the present system.

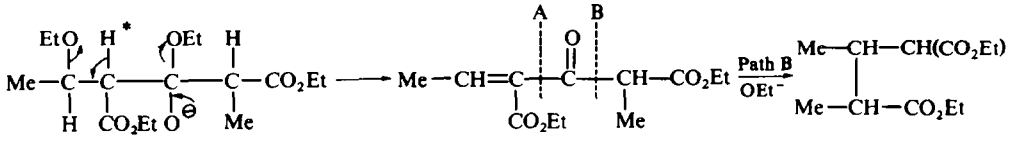
The dipole moment of cyanodicarboxylic ester XXI in benzene solution was found to be 3·13 D. Using the group moments: CN = 3·56 D,[25] CO_2Et = 1·94 D,[48] and CH_2CO_2Et = 1·86 D,[41] and assuming that the bond vector of the latter group is axial at C_2 one can calculate a value of 2·12 D for the moment of XXI. Calculated moments for structures in which the acetate group is equatorial (5·16 D) are much too high and eliminate such structures from consideration. The observed moment can be explained readily if the carbethoxyl group of the acetate is oriented away from the ring (as seems reasonable if it is to avoid unfavourable 1,3-diaxial interactions) so that the resultant moment is not antiparallel to that of the cyano group.



XXXIV

Summarizing the results of this study it may be suggested that in protic solvents the reversible addition of a malonate anion to an activated olefin under conditions of kinetic control involves product development control, the favoured path being that which leads to the intermediate of lowest energy. In a non-protic solvent, the transition state is more like the ground state and the preferred path will be governed to a large extent by the ease of approach of the nucleophile to the olefinic double bond. If the resonance-stabilized intermediate is not further stabilized by protonation reversal of the addition can take place readily; alternatively, rearrangement may take place irreversibly with molecules having suitable conformations, to give thermodynamically more stable products.

* This does not rule out the intervention of ethoxide ion in the "abnormal" additions in ethanol in other cases. It should be pointed out, however, that cleavage B followed by addition[39] is mechanistically equivalent to the formation of a 4-membered transition state, unless the process is a two-step one, which seems energetically unlikely:



XXXII XXXIII

Also, the proton (H*) adjacent to the activating group present in XXXII which is necessary for the elimination of ethanol to give XXIII is not present in our starting material VII.

The stereochemistry of the irreversible addition of methylmagnesium bromide to 5-methyl-2-cyclohexenone has been examined recently.[42] The product was *trans*-3,5-dimethylcyclohexanone, the formation of which was rationalized as above by considering the stabilities of the various possible intermediates and assuming that the transition state resembled the intermediate in geometry.

EXPERIMENTAL

M.ps are uncorrected. IR spectra were measured on a Perkin Elmer Model 21 instrument with NaCl optics. Only the main bands are reported. NMR spectra were determined on Varian A-60 and HA-100 instruments using TMS as the internal standard.

4-t-Butylcyclohexanone cyanohydrin

(a) *With sulphuric acid* (cf. Cox and Stormont[43]). To a vigorously stirred soln of 95% NaCN (134 g) in water (336 ml) cooled in an ice-bath was added 4-t-butylcyclohexanone (400 g). A white semi-solid formed immediately and 40% H_2SO_4 (560 ml) was added slowly (2 hr). The mixture was stirred for an additional 2 hr at 40°, the white semi-solid was filtered off and dissolved in ether (300 ml). The aqueous filtrate was extracted with ether (3 × 50 ml), the combined ethereal solns were washed with 20% $NaHSO_3$ aq (3 × 150 ml) and then $NaHCO_3$ aq (2 × 100 ml) and dried ($MgSO_4$). The solvent was evaporated and the residual yellow oil (400 g) crystallized on cooling. Recrystallization from light petroleum (b.p. 40–45°) gave what was clearly a mixture of 4-t-butylcyclohexanone and 4-t-butylcyclohexanone cyanohydrin (300 g), m.p. 40–48°. IR spectrum (Nujol mull): 3190 (m) (vbr), 2200 (w), and 1710 cm^{-1} (m).

(b) *With hydrochloric acid* (cf. Billimoria and Maclagan[44]). Conc HCl (292 ml) was added dropwise (2·5 hr) with stirring to a cooled (0°) mixture of 4-t-butylcyclohexanone (200 g) and powdered 96% NaCN (98 g) in ether (465 ml) and water (100 ml). Stirring at 0° was continued for 2·5 hr after which the ether layer was decanted and washed with a sat $NaHSO_3$ aq (2 × 70 ml) and dried ($MgSO_4$). Evaporation of the solvent gave the cyanohydrin as an oil (213 g, 90·5%) which crystallized on cooling and had m.p. 54–57°, b.p. 130–132°/7 mm (dec). (Found: C, 73·05; H, 10·68. Calc. for $C_{11}H_{19}NO$: C, 72·88; H, 10·57%); IR spectrum (Nujol mull): 3300 (s), 2220 (w), 1365 (s), 1125 (m), 1090 (s) and 1075 cm^{-1} (s). Munday[45] reports m.p. 53–54° for this cyanohydrin.

Di-(4-t-butyl-1-cyano)cyclohexyl sulphite

Thionyl chloride (11·8 g) was added over a period of 30 min to a vigorously stirred soln of 4-t-butylcyclohexanone cyanohydrin (15·6 g) in pyridine (13·4 ml) cooled in an ice and salt bath. The semi-solid mixture was stirred below 10° for another 3 hr and then treated with ice (150 g) and the organic layer removed. The aqueous layer was extracted with ether (3 × 20 ml) and the ether combined with the organic layer and dried ($MgSO_4$). The solvent was evaporated and the residue was recrystallized from EtOH to give *di-(4-t-butyl-1-cyano)cyclohexyl sulphite* (27·8 g, 79·5%), m.p. 110–111° (Found: C, 64·55; H, 8·89. $C_{22}H_{36}N_2O_3S$ requires: C, 64·68; H, 8·88%); IR spectrum (KBr disc): 2240 (w), 1400 (w), 1370 (s), 1225 (s), 810 (s), 765 (s), 736 (s), and 680 $^{-1}$ (m).

4-t-Butyl-1-cyanocyclohexene (VII)

(a) *With phosphorus oxychloride* (cf. Wheeler and Lerner[46]). To a vigorously stirred soln of 4-t-butylcyclohexanone cyanohydrin (3·6 g) in pyridine (5 ml) and benzene (5 ml) at 0° was added a soln of $POCl_3$ (6·5 ml) and pyridine (6 ml) dropwise. A white ppt separated. The mixture was heated slowly and eventually boiled under reflux for 35 min. The wine coloured soln was poured onto ice (100 g), extracted with ether (3 × 20 ml) and the combined extracts dried ($MgSO_4$). Evaporation of the solvent gave *4-t-butyl-1-cyanocyclohexene* as an oil which solidified and was recrystallized from EtOH to give colourless crystals (3·0 g, 92·5%), m.p. 45–46. (Found: C, 80·64; H, 10·29. $C_{11}H_{11}N$ requires: C, 80·92; H, 10·50%); IR spectrum (KBr disc): 2200 (m), 1632 (m), and 1365 cm^{-1} (s); NMR spectrum (CCl_4) τ: 3·5 (1H, broad singlet: 7·8 to 8·7 (7H, multiplet); 9·13 (9H, singlet).

(b) *From the sulphite.* To a vigorously stirred soln of the sulphite (2·5 g) in pyridine (5 ml) was added $SOCl_2$ (0·72 ml). The white ppt initially formed went into soln as the temp was raised to the b.p. The soln was poured into ice and worked up as above to give the unsaturated nitrile (2·2 g, 91·5%), m.p. 45–46°.

(c) *With thionyl chloride* (cf. McElvain and Starn[47]). $SOCl_2$ (155 g) was added dropwise over a period of 1 hr to a vigorously stirred soln of 4-t-butylcyclohexanone cyanohydrin (200 g) in pyridine (174 ml) which

was cooled in an ice-bath. When approximately half of the $SOCl_2$ had been added a semi-solid separated which made stirring difficult. The temp of the reaction mixture was raised to 25° and the addition of the $SOCl_2$ was continued. The mixture was then gradually heated to reflux temp and maintained there for 45 min. The hot soln was poured onto ice (1 kg), extracted with ether (3 × 200 ml) and the combined extracts were dried ($MgSO_4$). Evaporation of the solvent and distillation of the residual oil gave a fraction, b.p. 80–84°/0·6 mm, which crystallized on cooling. Recrystallization from EtOH gave the desired nitrile (99 g, 55%), m.p. 45–46°.

Diethyl trans-4-*t-butyl*(e)-1-*cyano*(e)-2-*cyclohexylmalonate*(e) (XI)

Freshly distilled diethyl malonate (75 g, 0·52 mole) was added under dry N_2 to a stirred soln of EtONa from Na (7·5 g, 0·33 mole) and abs EtOH (210 ml). 4-t-Butyl-1-cyanocyclohexene (27 g, 0·165 mole) was then added and the soln was boiled under reflux for 17 hr. It was then cooled, acidified with AcOH and washed with 5% $NaHCO_3$aq (3 × 15 ml), and then with a sat NaClaq (3 × 50 ml). The aqueous soln was extracted with ether (3 × 25 ml) and the combined ether extracts and organic phase were dried ($MgSO_4$). The solvent was evaporated and the residual oil was distilled. The fraction b.p. 150–154°/0·8 mm (38·2 g, 74%) was collected and was shown by GLC on an ethylene glycol succinate column (procedure described below) to consist of XXI and XI and XII in the ratio of 8:81:11. The desired trans-*cyanomalonate* XI, m.p. 86–87·5° (14 g, 26·4%) was obtained from the distillate by fractional crystallization from EtOH. (Found: C, 66·53; H, 8·81. $C_{18}H_{29}NO_4$ requires: C, 66·84; H, 9·04%.) IR spectrum (KBr disc): 2240(w), 1743(vs), 1727(s), 1365(m), 1268(s), 1258(s), 1188(s), 1170(s) and 1138 cm^{-1}(s); NMR spectrum (CCl_4) at oscillator frequency of 60 mc/s, τ: 5·82 (4H quartet, J = 7 c/s; at 100 mc/s each peak of quartet appears as triplet, J = 1 to 2 c/s), 6·48 (1H doublet, J = 12 c/s), 7·12 and 7·35 (2H, overlapping broad singlets), 8·4 (7H, broad multiplet), 8·73 (6H triplet, J = 7 c/s), and 9·14 (9H singlet).

Diethyl cis-4-*t-butyl*(e)-1-*cyano*(a)-2-*cyclohexylmalonate*(e) (XII)

Freshly distilled diethyl malonate (53·4 g, 0·334 mole) was added under dry N_2 to a stirred soln of EtONa [from Na (3·84 g, 0·167 mole) in abs EtOH (200 ml)] and the resulting soln was stirred at room temp (under N_2 and $CaCl_2$ guard tube) for 5 days. The soln was then acidified with glacial AcOH, extracted with ether, and worked up as described above for the *trans*-isomer. Gas chromatography on an ethylene glycol succinate column showed the crude mixture to contain starting material, together with XXI, XI and XII in the ratio of 4:30:66, the products being formed in an overall yield of 4·5%. Unreacted 4-t-butyl-1-cyanocyclohexene (35 g, 73%) could be recovered by fractional crystallization of the mixture from light petroleum (b.p. 40–45°), and some of the low boiling material was removed under reduced press below 110° at 12 mm. The crude residue (15 g), still containing some starting material, was dissolved in light petroleum (b.p. 40–50°; 20 ml) and chromatographed on a column of alumina (110 g, 14 in. × 1 in.) which had been prewashed with light petroleum. Elution with light petroleum (b.p. 40–45°; 150 ml) gave a mixture of recovered starting material, XXI and XI. Elution with light petroleum (b.p. 60–80°)–benzene (4:1 v/v) (1200 ml) gave XII (1·7 g, 1·72%), m.p. 71·5–73°, after recrystallization from light petroleum (b.p. 40–45°). (Found: C, 67·13; H, 8·95. $C_{18}H_{29}NO_4$ require: C, 66·84; H, 9·04%); IR spectrum (KBr): 2240 (w), 1750 (m), 1730 (vs), 1365 (m), 1295 (s), 1230 (s), 1222 (s), 1175 (s) and 1150 cm^{-1} (s); NMR spectrum (CCl_4) at oscillator frequency of 60 mc/s, τ: 5·78 (4H quartet, J = 7 c/s. At 100 ms/s each peak of the quartet appears as a doublet, J = 3 c/s), 6·43 (1H doublet, J = 11 c/s), 7·19 (2H broad multiplet), 8·09 (7H multiplet), 8·71 (6H triplet, J = 7 c/s), and 9·17 (9H singlet).

Ethyl 4-*t-butyl*(e)-2-*carbethoxymethyl*(a)-1-*cyano*(a)*cyclohexanecarboxylate*(e)—*Cyanodicarboxylic ester* (XXI)

A dispersion of Na (5·04 g, 0·218 mole) in toluene [prepared by stirring Na (5·04 g) in dry toluene (150 ml) at 110° for 2 min in a Waring blendor] was added slowly, under dry N_2, to a stirred soln of freshly distilled diethyl malonate (39·4 g, 0·248 mole) in dry toluene (230 ml). The resulting mixture was gradually heated and kept at reflux temp until all the Na had reacted (3 hr). 4-t-Butyl-1-cyanocyclohexene (50 g, 0·306 mole) in dry toluene (20 ml) was slowly added to the stirred suspension and the resulting mixture was boiled under reflux for 42 hr. Toluene (300 ml) was distilled off over a period of 6 hr. The clear, wine-coloured soln was cooled, acidified with glacial AcOH, diluted with water (200 ml), the organic layer neutralized with Na_2CO_3 and washed with water (3 × 100 ml). The combined ether extracts and organic layer were dried ($MgSO_4$) and the solvent evaporated to give an oil, shown by GLC on an ethylene glycol succinate column to contain starting materials, together with XXI and *trans*- XI and *cis*-XII in the ratio of

91:6:3, respectively. Fractional distillation gave unreacted 4-t-butyl-1-cyanocyclohexene (27 g, 65%), b.p. 78–94°/0·11 mm, and the isomeric cyanoesters (15·6 g, 17·4%), b.p. 140–150°/0·12 mm, which crystallized on cooling. Fractional crystallization from light petroleum (b.p. 40–50°) gave the *cyanodicarboxylic ester* (XXI; 8·8 g, 10·9%), m.p. 50–52°. The same compound could be obtained in much lower recovery (1·4 g), by chromatographing the distillate on a column of alumina (110 g) which had been prewashed with light petroleum, and eluting with benzene. (Found: C, 66·99; H, 8·89. $C_{18}H_{29}NO_4$ requires: C, 66·84; H, 9·04%); IR spectrum (KBr disc): 2250 (vw), 1748 (vs), 1734 (m), 1375 (m), 1285 (m), 1245 (vs), 1195 (m), 1150 (m) and 1028 cm^{-1} (s); NMR spectrum (CCl_4) at 60 mc/s, τ: 5·72 and 5·89 [quintet due to superposition of two quarters; at 100 mc/s a 1:3:4:4:3:1 sextet was observed due to superposition of two quartets at 5·72 (2H quartet, J = 7 c/s) and 5·89 (2H quartet, J = 7 c/s)], 7·55 to 7·78 (1H broad singlet), 7·7 (2H singlet), 7·78 to 8·47 (7H multiplet), 8·65 and 8·75 [6H quartet due to superposition of two triplets; at 100 mc/s, the triplets were resolved: 8·65 (3H triplet, J = 7 c/s and 8·75 (3H triplet, J = 7 c/s)], and 9·09 (9H singlet).

Deuteration of trans-*cyanomalonate* (XI)

Cyanomalonate XI (0·41 g) in abs EtOH (2 ml) and EtONa [from Na (0·036 g) in EtOH (4 ml)] were stirred at room temp for 30 min, and then evaporated to dryness under reduced press. The solid residue was treated with D_2O (2 ml), the mixture was stirred for 10 min, extracted with dry CCl_4 (3 × 10 ml) and the extracts dried ($MgSO_4$). Evaporation of the solvent gave the deuterated malonate (0·35 g, 85·5%), which was shown to be pure by GLC; IR spectrum (KBr disc): 2240 (w), 1745 (vs), 1730 (s), 1370 (m), 1260 (vs), 1240 (s), and 1120 cm^{-1} (s). No line was present at 6·48 τ in the NMR spectrum.

A similar attempted deuteration of XXI gave unchanged starting material.

Methylation of trans-*cyanomalonate* (XI)

To a cooled (0°) suspension of EtONa [from Na (0·044 g) in abs EtOH (3 ml) and then evaporated to dryness] in dry ether (3 ml) was added *trans*- XI (0·528 g). 5 min later, MeI (2·84 g) was added and the resulting soln was allowed to stand at room temp for 3 hr. It was treated with water (10 ml), taken up in ether (3 × 10 ml) and the combined extracts dried ($MgSO_4$). The oil remaining (0·40 g, 73%) after evaporation of the solvent crystallized on cooling and was recrystallized from light petroleum (b.p. 40–45°) to give *diethyl* trans-*4-t-butyl-1-cyano-2-cyclohexylmethylmalonate*, m.p. 58–59° (Found: C, 67·41; H, 9·56. $C_{19}H_{31}NO_4$ requires: C, 67·62; H, 9·26%); IR spectrum (KBr): 2240 (w), 1748 (m), 1735 (vs), 1375 (m), 1255 (s), 1230 (s), 1120 (s), and 1015 cm^{-1} (m); NMR spectrum (CCl_4), τ: 5·82 (4H quartet, J = 7 c/s), 6·91 to 7·5 (2H multiplet), 8·42 (7H multiplet), 8·6 (3H singlet), 8·74 (6H triplet, J = 7 c/s), 9·12 (9H singlet). Attempted methylation of XXI gave only recovered starting material.

Molar extinction coefficients for the nitrile absorption bands of trans- *and* cis-*cyanomalonates* (XI *and* XII) (cf. Nagata *et al.*[22])

These were measured on CCl_4 solns of the compounds in matched NaCl cells of path length 0·1 cm at 2240 cm^{-1}. The results are summarized in Table 3.

TABLE 3. $\varepsilon_{C\equiv N}$ FOR *trans*- (XI) AND *cis*-CYANOMALONATE (XII)

Isomer	Optical density	Conc. (moles/l)	ε
trans- XI	0·279	0·1129	24·71
cis- XII	0·259	0·1169	22·16

Determination of isomer ratios for additions in various solvents and with varying amounts of catalysts by gas chromatography

The reactions were carried out as described above for additions carried out in EtOH or in toluene soln. The most satisfactory separation by GLC of the reaction products was effected using the following conditions:

Column 4 ft × ¼ in. packed with ethylene glycol succinate (17% by wt) on Chromosorb W (60–80 mesh) which was precoated with polyvinylpyrrolidone (1% by wt). It was found best to prepare the ethylene

glycol succinate by the procedure of Craig and Murty[48] to obtain reproducible results since commercially available substrates varied in their quality and stability. Column temp: 193°, He flow rate: 60 ml/min. Retention times: 4-t-butyl-1-cyanocyclohexene, 1·8 min; *trans*-cyanoacetate VIII, 10·6 min; *cis*-cyanoacetate (IX), 11·6 min; cyanodicarboxylic ester (XXI), 19·6 min; *trans*-cyanomalonate (XI), 29·0 min; *cis*-cyanomalonate (XII), 32·3 min. Calibration curves were prepared plotting area v/s concentration for all of these compounds. The results of the isomer ratio determinations are summarized in Table 1.

Variation of isomer ratio with time

The reactions were carried out as before except that aliquots (10–20 ml) were removed at various intervals of time and acidified, extracted, the solvent evaporated and the products analyzed by gas-chromatography on a 6 ft × ¼ in. column packed with Apiezon M (20% w/w) on Gas-Chrom P (60–80 mesh) operated at 212° and using a He flow rate of 100 ml/min. Under these conditions the retention times were as follows: cyanodicarboxylic ester (XXI), 37·0 min; *trans*-cyanomalonate (XI), 41·0 min; *cis*-cyanomalonate (XII), 45·5 min. Calibration curves plotting area v/s concentration were prepared for each compound. The results of the runs are summarized in Table 2.

Equilibration of cyanomalonates (XI and XII)

Diethyl malonate (0·20 g) and *trans*-cyanomalonate (XI; 0·25 g) were added to a soln of EtONa [from Na (0·023 g) and abs EtOH (10 ml)] under dry N_2 and the resulting soln was boiled under reflux for 64 hr. It was then cooled and worked up in the usual manner. The equilibrations of the *cis*-cyanomalonate were carried out analogously except that the following quantities of materials were used: Na (0·008 g), EtOH (4 ml), diethyl malonate (0·05 g), and XII (0·06 g). The product ratios were determined by gas chromatography on the ethylene glycol succinate column. The results are summarized below in Table 4.

TABLE 4. BASE-CATALYZED EQUILIBRATIONS OF THE CYANOMALONATES

Starting cyanomalonate	Ratio of isomers XXI : XI : XII	Yield %	Ratio of cyanoacetates VIII : IX	Yield %	4-t-Butyl-1-cyanocyclohexene %
trans- XI	11·1 : 78·5 : 10·4	71	57 : 43	23	5
cis- XII	4 : 86·8 : 9·2	74	61 : 39	20·6	5

Dipole moments of cyanodicarboxylic ester (XXI) *and* trans- XI *and* cis-*cyanomalonate* (XII)

The electrical polarization data for the compounds in benzene soln at 20° were kindly obtained for us by Dr. G. F Wright. The results are summarized in Table 5. The symbols and calculations are as those given by Smith.[49]

TABLE 5. ELECTRICAL POLARIZATION DATA

Compound	In benzene soln at 20°							
	m.p.	$\frac{d\varepsilon}{dw}$	$\frac{dv}{dw}$	ε_0	$\varepsilon_{extr.}$	V_0	V_{extr}	P_T(cc)
XXI	50–52°	3·40	−0·166	2·2801	2·2802	1·13785	1·3774	299
XI	86–87·5°	8·61	−0·176	2·2801	2·2796	1·13785	1·3783	614
XII	71·5–73°	6·12	−0·186	2·2801	2·2801	1·13875	1·3780	461

Compound	Polarization of solids			MR_D	Dipole moments (*D*)	
	Density	ε	P_D(cc)		μ_{P_D}	μ_{MR_D}
XXI	1·1341	2·430	92·1	87·2	3·13	3·17
XI	1·1303	2·524	96·4	87·2	3·13	3·17
XII	1·1237	2·452	94·0	87·2	4·17	4·21

trans-4-*t*-*Butyl*-2-*carboxymethylcyclohexane cyanide* (X)

trans-Cyanomalonate (XI) (1·0 g) was added to 10% Na_2CO_3 aq (4 ml) containing acetone (3 ml) and the mixture was boiled under reflux for 17 hr, cooled, diluted with water (10 ml) and extracted with ether (3 × 10 ml). The aqueous layer was made just acid with 0·1N HCl saturated with NaCl, extracted with ether and the combined ether extracts dried ($MgSO_4$). The solvent was evaporated and the residual oil was heated to 170° until the evolution of CO_2 ceased (10 min). The oil (0·42 g, 61%) crystallized on coolIng and, on recrystallization from benzene–light petroleum (b.p. 40–45°) gave trans-4-*t*-*butyl*-2-*carboxylmethylcyclohexane cyanide*, m.p. 123–124°. (Found: C, 70·18; H, 9·46. $C_{13}H_{21}NO_2$ requires: C, 69·92; H, 9·48%); IR spectrum (KBr): 3300–2500 (v br, m), 2220 (w), 1715 (s), 1375 (m), 1320 (m), 1225 (s) and 927 cm^{-1} (m); NMR spectrum (pyridine), τ: 6·61 (1H, poorly resolved quartet, J = 4 c/s), 7·02–7·25 (1H multiplet), 7·12 (2H singlet), 8·21–9·0 (7H multiplet), 9·14 (9H singlet).

trans-4-*t*-*Butyl*-2-*carbethoxymethylcyclohexane cyanide* (VIII)

(a) *By decarbethoxylation of* trans-*cyanomalonate* (XI). The *trans*-XI (4·0 g) was added to a stirred soln of EtONa [from Na (1·14 g) in abs EtOH (110 ml)] under dry N_2. The soln was stirred at room temp for 96 hr, acidified with glacial AcOH, washed with 5% $NaHCO_3$ aq and then with a sat NaCl aq (3 × 25 ml). The aqueous layer was extracted with ether (3 × 15 ml) and the combined extracts dried ($MgSO_4$) and evaporated. The reddish-brown oil was resolved by preparative gas chromatography on an ethylene glycol succinate column. The major product was trans-4-*t*-*butyl*-2-*carbethoxymethylcyclohexane cyanide*, b.p. 96–98/0·1 mm. (Found: C, 71·54; H, 9·87. $C_{15}H_{25}NO_2$ requires: C, 71·67; H, 10·03%); IR spectrum (CCl_4): 2240 (w), 1730 (vs), 1306 (m), 1182 (m) and 1165 cm^{-1} (s); NMR spectrum (CCl_4), τ: 5·88 (2H quartet, J = 7 c/s), 7·21 (1H singlet), 7·4–7·8 (1H multiplet), 7·6 (2H singlet), 8·41 (7H multiplet), 8·74 (3H triplet, J = 7 c/s) and 9·13 (9H singlet). The ester was very hygroscopic. The gas chromatographic analysis indicated the presence of 4-*t*-butyl-1-cyanocyclohexane and of the *cis*- and *trans*-cyanomalonates in the reaction mixture, but none of the *cis*-cyanoacetate.

(b) *By esterification of the acid.* A soln of *trans*-4-t-butyl-2-carboxymethylcyclohexane cyanide (0·63 g) in $SOCl_2$ (0·25 g) was heated at 40–50° for 1 hr, the excess $SOCl_2$ was removed *in vacuo* and the acid chloride was dissolved in dry ether (1 ml) and added to a soln of abs EtOH (3 ml) and pyridine (0·49 g). The soln was heated at 45° for 1 hr, cooled, diluted with water (15 ml), saturated with NaCl, extracted with ether (3 × 5 ml), and the combined extracts dried ($MgSO_4$). The solvent was evaporated and the residual oil distilled to give the *trans*-cyanoacetate (0·41 g, 58%), b.p. 94°/0·05 mm, identical with that obtained above.

cis-4-*t*-*Butyl*-2-*carbethoxymethylcyclohexane cyanide* (IX)

This was prepared by decarbethoxylation of XII as described for the *trans*-isomer above and collecting the cis-*cyanoacetate*, b.p. 96–98°/0·1 mm by preparative gas phase chromatography. Like the *trans*-isomer, this *cis*-compound was very hygroscopic and proved difficult to analyze. (Found: C, 72·14; H, 9·84. $C_{15}H_{25}NO_2$ requires: C, 71·67; H, 10·03%); IR spectrum (CCl_4): 2240 (w), 1732 (vs), 1320 (m), 1300 (w), 1182 (m) and 1152 cm^{-1} (m).

Equilibration of trans-4-*t*-*butyl*-2-*carbethoxymethylcyclohexane cyanide*

The ester (0·060 g) was boiled under reflux with ethanolic EtONa [from Na (0·010 g) and abs EtOH (10 ml)] for 3 hr. The cooled soln was acidified with glacial AcOH and worked up in the usual manner. Gas chromatographic analysis was effected on an Apiezon M (25% w/w) on Chromosorb W column (7 ft × ¼ in.) operated at 218° with a He flow rate of 120 ml/min. Under these conditions, *cis*- and *trans*-4-t-butyl-2-carbethoxymethylcyclohexane cyanide have the same thermal response. The *cis*:*trans* ratio obtained was 34:66.

trans-4-*t*-*Butyl*-2-*carboxymethylcyclohexanecarboxylic acid* (XV)

(a) *trans*-XI (1·0 g) in 3N HCl (30 ml) was boiled under reflux for 4 days. The cooled soln was extended with ether (3 × 10 ml), the combined extracts were dried ($MgSO_4$) and the solvent evaporated. The solid residue was washed with light petroleum (b.p. 40–50°) (50 ml) and the solid (0·3 g, 40%) was recrystallized from ether–light petroleum (b.p. 40–45°) to give trans-4-*t*-*butyl*-2-*carboxymethylcyclohexanecarboxylic acid*, m.p. 180–182°. (Found: C, 64·47; H, 9·18. $C_{13}H_{22}O_4$ requires C, 64·44; H, 9·15%); IR spectrum (KBr): 3300–2500 (m), 1718 (s), 1708 (s), 1356 (m), 1290 (s), 1160 (m), and 928 cm^{-1} (m); NMR spectrum of the Na salt was measured in D_2O, but all the important bands overlapped those of the ring protons.

The pK_as were determined by dissolving the acid in methylcellosolve (80%) and titrating the soln with 0·01N NaOH. $pK_1 = 6·45$; $pK_2 = 7.22$.

(b) A sol of *trans*-XI (5 g) in 12N HCl (20 ml) was boiled under reflux for 3 days, during which time a white solid precipitated. The reaction mixture was cooled to 10°, the solid filtered, washed with cold water (50 ml) and dried (3·1 g, 83%), m.p. 140–165°. It was shown by gas-chromatography of the methyl esters to consist of a mixture of the *cis*- and the *trans*-dicarboxylic acids in the ratio of 42:58. The free acids could not be resolved by column or TLC on silica gel. The mixture was washed with boiling water (14 × 50 ml) and the insoluble portion was recrystallized repeatedly from acetone and once from light petroleum (b.p. 40–45°) to yield a solid (0·5 g), m.p. 210–212°, identical with an authentic sample of the *cis*-dicarboxylic acid.

Methyl trans-4-*t*-*butyl*-2-*carbomethoxymethylcyclohexanecarboxylate* (XVII)

To a cooled (0°) soln of the *trans*-dicarboxylic acid (0·30 g) in abs MeOH (2 ml) was added an ethereal soln of diazomethane until a definite yellow colour persisted in the soln. The excess diazomethane was allowed to evaporate and the solvent removed to give *methyl* trans-4-*t*-*butyl*-2-*carbomethoxymethylcyclohexanecarboxylate*, b.p. 112°/0·4 mm. (Found: C, 66·07; H, 9·8. $C_{15}H_{26}O_4$ requires: C, 66·63, H, 9·69%); IR spectrum (liquid film): 1732 (vs), 1362 (m), 1260 (m), 1190 (s), 1160 (s), and 1140 cm^{-1} (s); NMR spectrum (CCl_4) at 100 mc/s, τ: 6·32 (3H singlet), 6·36 (3H singlet), 7·24 (1H, unresolved doublet, $J \simeq 4$ c/s), 7·58 (2H doublet, $J = 5$ c/s), 7·7 (1H doublet, $J = 4·8$ c/s), 8·6 (7H multiplet), and 9·19 (9H singlet).

trans-4-*t*-*Butyl*-2-*carboxymethylcyclohexanecarboxylic acid anhydride* (XVI)

The *trans*-dicarboxylic acid (0·102 g) and Ac_2O (6 ml) were boiled under reflux for 5 hr. The excess Ac_2O was removed under reduced press (10 mm) at 100°. The residue was recrystallized from dry ether–light petroleum (b.p. 40–45°) to give the trans-*anhydride* (0·049 g, 51·5%, m.p. 58–59°. (Found: C, 69·48; H, 8·92. $C_{13}H_{20}O_3$ requires: C, 69·61; H, 8·99%); IR spectrum (KBr disc): 1808 (s), 1765 (vs), 1362 (m), 1262 (w), 1110 (s), 1065 (vs), and 990 cm^{-1} (s); NMR spectrum (CCl_4) at 100 mc/s, τ: 7·0–8·65 (11H, complex multiplet), 9·03 (9H singlet).

cis-4-*t*-*Butyl*-2-*carboxymethylcyclohexanecarboxylic acid* (XVIII)

cis-XII (0·200 g) in 3N HCl (10 ml) was boiled under reflux for 3 days. The solid which precipitated was washed with cold water (20 ml) and recrystallized from water to give the cis-*dicarboxylic acid* (0·093 g, 62%), m.p. 210–212°. (Found: C, 64·74, H, 8·78. $C_{13}H_{22}O_4$ requires: C, 64·44; H, 9·15); IR spectrum (KBr) 3300–2500 (m), 1720 (vs), 1965 (s), 1360 (m), 1280 (s), and 880 cm^{-1} (m). The pK_as were determined by dissolving the acid in methylcellosolve (80%) and titrating the soln with 0·01N NaOH. $pK_1 = 6·32$; $pK_2 = 7·19$.

Methyl cis-4-*t*-*butyl*-2-*carbomethoxymethylcyclohexanecarboxylate* (XIX)

This was prepared from the *cis*-dicarboxylic acid (0·30 g) in the same way as was the *trans*-ester. The product (0·26 g, 78%) had b.p. 120/0·9 mm. (Found: C, 66·69; H, 9·80. $C_{15}H_{26}O_4$ requires: C, 66·63, H, 9·69%); IR spectrum (liquid film): 1734 (vs), 1715 (m). 1362 (m), 1255 (m), 1190 (s), and 1165 cm^{-1}(s); NMR spectrum (CCl_4), τ: 6·37 (6H singlet), 7·43 (1H, broad singlet), 7·69 (2H singlet), 7·8 (1H singlet), 8·2 to 8·9 (7H multiplet), and 9·16 (9H singlet).

cis-4-*t*-*Butyl*-2-*carboxymethylcyclohexanecarboxylic acid anhydride* (XX)

The *cis*-dicarboxylic acid (0·094 g) was heated with Ac_2O as described for the *trans*-isomer and the cis-*anhydride* (0·039 g, 51%) (from dry ether–light petroleum) had m.p. 113·5–115°. (Found: C, 69·50; H, 9·00. $C_{13}H_{20}O_3$ requires: C, 69·61; H, 8·99%); IR spectrum (KBr): 1810 (s), 1764 (vs), 1370 (m), 1255 (m), 1245 (s), 1160 (s), 1110 (vs), 1080 (s), and 950 cm^{-1} (s); NMR spectrum (CCl_4): there appears to be an AB quartet at τ_A 7·34 and τ_B 7·39 ($J_{AB} = 16·5$ c/s); however, there are two other protons overlapping this quartet. The ring protons gave a complex multiplet and a 9H singlet was observed at 9·12 τ.

Relative rates of anhydride formation from cis- *and* trans-4-*t*-*butyl*-2-*carboxymethylcyclohexanecarboxylic acid*

Aliquots (50 µl) of solns of each of the dicarboxylic acids (0·010 g) in acetone (400 µl) were injected in the gas chromatograph using a 1·5 ft. × ¼ in. column packed with SE 30 (10% w/w) on firebrick (60–80 mesh) at a temp of 175° (injector temp 205°) and a He inlet press of 20 p.s.i. Both compounds had retention times of 2 min. Under these conditions, and using the authentic anhydrides, it was shown that the peak

height was proportional to the anhydride concentration and that both anhydrides had the same thermal response. Peak height could then be taken as a measure of the amount of anhydride formation after passage through the column for 2 min under the above conditions. The mean of a number of runs were taken and the relative rates of formation of *cis*- and *trans*-anhydrides were thus found to be in the ratio of 13·7:5·3. If Ac_2O was added to the solns prior to injection into the gas-chromatograph anhydride formation was complete and equal amounts of products were formed from both dicarboxylic acids, probably in the injection region of the chromatograph.

Equilibrium of methyl trans-4-*t-butyl*-2-*carbethoxymethylcyclohexanecarboxylate* (XVII)

The *trans*- XVII (0·027 g) and 10% Pd–C (0·008 g) were heated at 240° ±4° for 29 hr. The products were analyzed by GLC on a 4 ft. × ¼ in. ethylene glycol succinate (10% w/w) on Chromosorb W (60–80 mesh) column operated at 174°, with a He flow rate of 45 ml/min. Under these conditions the *trans*-ester had a retention time of 10·3 min and XIX a retention time of 12·3 min. Calibration curves were prepared using standard solns of the pure esters. The *cis*- : *trans*-ratio was thus found to be 17:83.

4-*t-Butyl*(e)-2-*carboxymethyl*(a)-1-*cyano*(a)*cyclohexanecarboxylic acid* (e) (XXII)

Compound XXI (1·0 g) in 10% Na_2CO_3 aq (8 ml) and acetone (4 ml) was boiled under reflux for 24 hr. The cooled suspension was filtered from some insoluble material and the soln made just acid with N HCl. The soln was extracted with ether (3 × 10 ml) and the combined extracts dried ($MgSO_4$) and evaporated to give 4-*t-butyl*(e)-2-*carboxymethyl*(a)-1-*cyano*(a)*cyclohexanecarboxylic acid* (0·35 g, 42%), m.p. 205–207° after recrystallization from ether–light petroleum (b.p. 40–45°). (Found: C, 62·85; H, 8·07. $C_{14}H_{21}NO_4$ requires: C, 62·90; H, 7·92%); IR spectrum (KBr): 3300–2500 (m), 2240 (w), 1725 (vs), 1700 (m), 1375 (m), 1290 (m) and 925 cm^{-1} (m).

4-*t-Butyl*(e)-2-*carboxymethyl*(a)-1-*cyano*(a)*cyclohexanecarboxylic acid*(e) *anhydride* (XXIII)

The above dicarboxylic acid (0·05 g) and Ac_2O (6 ml) was boiled under reflux for 4 hr. The excess Ac_2O was removed at 10 mm on a steam-bath and the residue was recrystallized from ether–light petroleum (b.p. 40–45°) to give the *anhydride* (0·029 g, 63%), m.p. 138–139°. (Found: C, 67·60; H, 7·80. $C_{14}H_{19}NO_3$ requires: C, 67·44; H, 7·68%); IR spectrum (KBr): 2238 (w), 1820 (s), 1760 (vs), 1365 (m), 1230 (s), 1142 (s), 1070 (vs), and 1005 cm^{-1} (s); NMR spectrum (CCl_4) at 100 mc/s: an AB quartet at τ_A 7·13 and τ_B 7·29 (J_{AB} = 6 c/s). A single proton peak at 7·07 overlapped the quartet. The ring protons gave rise to a complex multiplet. The t-Bu group gave the usual 9H singlet at 9·08 τ.

Acid hydrolysis of cyanodicarboxylic ester (XXI)

(a) *With dilute hydrochloric acid.* On boiling the ester with 3N HCl for 6 days (as described for the cyanomalonates) only a syrupy brown oil could be isolated, hydrolysis being incomplete.

(b) *With* 12N *hydrochloric acid.* Compound XXI (1·6 g) and 12N HCl (12 ml) were boiled under reflux for 3 days, during which time a solid precipitated. The reaction mixture was cooled to 10° and the solid filtered and washed with cold water (50 ml). A sample of the crude acid (0·01 g) was methylated as described below and analyzed by gas-chromatography which showed this product to be a single compound. Recrystallization of the acid from ether–light petroleum (b.p. 40–45°) gave 4-t-*butyl*(e)-2-*carboxymethyl*(a)-*cyclohexanecarboxylic acid*(e) (0·804 g, 67%), m.p. 190–192°. (Found: C, 64·30; H, 8·99. $C_{13}H_{22}O_4$ requires: C, 64·44; H, 9·15%); IR spectrum (KBr): 3300–2500 (m), 1732 (vs), 1710 (s), 1375 (m), 1270 (m), 1240 (m), 1220 (m), and 894 cm^{-1} (m).

Methyl 4-*t-butyl*(e)-2-*carbomethoxymethyl*(a)*cyclohexanecarboxylate*(e) (XXV)

The above dicarboxylic acid (0·40 g) was esterified with diazomethane as described for *trans*-XV. Distillation of the product gave the desired *dimethyl ester* (0·375 g, 84%), b.p. 112°/0·85 mm. (Found: C, 66·48; H, 9·17. $C_{15}H_{26}O_4$ requires: C, 66·63; H, 9·69%); IR spectrum (liquid film): 1735 (vs), 1720 (m), 1362 (m), 1255 (m), 1158 (s), 1028 (w), and 1015 cm^{-1} (w); NMR spectrum (CCl_4) at 100 mc/s, τ: 6·39 (6H singlet), 7·73 to 9·0 (11H multiplet), 9·13 (9H singlet).

4-*t-Butyl*(e)-2-*carboxymethyl*(a)*cyclohexanecarboxylic acid*(e) *anhydride* (XXVI)

The above dicarboxylic acid (0·103 g) and Ac_2O (6 ml) were boiled under reflux for 4 hr and the mixture worked up in the usual way. Recrystallization from ether–light petroleum (b.p. 40–45°) gave the *anhydride* (0·049 g, 51·5%), m.p. 97–98°. (Found: C, 69·60; H, 8·82. $C_{13}H_{20}O_3$ requires: C, 69·61; H, 8·99%); IR

spectrum (KBr): 1810 (s), 1752 (vs), 1362 (m), 1250 (m), 1215 (s), 1064 (s), 1050 (vs), and 996 cm^{-1} (s); NMR spectrum (CCl_4) at 100 mc/s, τ: 7·18 and 7·6 (2H, AB quartet, J_{AB} = 17 c/s; A side of quarter: each peak is a doublet, J = 4 c/s, B side of quartet: each peak is a doublet, J = 11·9 c/s), 7·5 to 7·8 (2H multiplet), 7·8 to 9·0 (7H multiplet), 9·12 (9H singlet).

The relative rates of formation of this and of the corresponding 1-cyano-anhydride were compared using the gas-chromatographic method described above. Both anhydrides had retention times of 2 min and both appeared to be formed with equal ease and almost three times faster than the anhydride from *trans*-XV.

Isomer ratios in the addition of diethyl malonate to 1-cyanocyclohexene

(a) The mixture of *cis*- and *trans*-diethyl 2-cyanocyclohexylmalonate (15·4 g), prepared under the conditions described,[11] partly crystallized after standing at −5° for a few days. The crystals were filtered off and the remaining liquid was allowed to stand at −5° when the sample again partly crystallized. This procedure was repeated 3 times to give a total of 6·45 g of the crystalline *trans*-isomer. The liquid portion (8·9 g) was shown by gas chromatography to consist of approximately equal amounts of the *cis*- V and *trans*- VI isomers. The *cis* : *trans*- ratio in the original mixtures was, therefore, approximately 30:70.

(b) A very large number of columns and conditions were tried in attempts to resolve *cis*- and *trans*-diethyl 2-cyanocyclohexylmalonate by gas chromatography. The best conditions, which only led to incomplete resolution, and hence to only approximate semi-quantitative results were the following: 10 ft. × ¼ in. column packed with Apiezon M (0·25% w/w) on glass beads (60–80 mesh) operated at 200°, with an injector temp of 250° and a He flow rate of 60 ml/min. Under these conditions, the *trans*-isomer had a retention time of 42 min. The results are summarized below.

All the reactions in EtOH yielded a small amount of *cis*- and of *trans*-ethyl 2-cyanocyclohexylacetate in about equal proportions.

Reaction No.	Solvent	Molar ratios of			Approximate isomer ratio *cis*- V : *trans*- VI
		Sodium	Diethyl malonate	1-Cyanocyclo-hexene	
26	Ethanol	2	3	1	30 : 70
27	Ethanol	1	2	1	15 : 85
28	Ethanol	1	1	1	5 : 95
29	Ethanol	1/3	1	1	5 : 95
30	Toluene	2	3	1	80 : 20
31	Toluene	1	2	1	80 : 20
32	Toluene	1	1	1	90 : 10
33	Toluene	1/3	1	1	95 : 5

trans-*Ethyl 2-cyanocyclohexylacetate*

trans-Diethyl 2-cyanocyclohexylmalonate (1 g) and EtONa in EtOH [from Na (0·218 g) and EtOH (50 ml)] were kept at room temp for 48 hr. The soln was then acidified with glacial AcOH, washed with water, the aqueous layer extracted with ether (3 × 5 ml), the combined organic layers dried ($MgSO_4$) and the solvent distilled. The crude residue was analyzed by gas chromatography and shown to contain a small amount of the unchanged *trans*-diethyl 2-cyanocyclohexylmalonate together with a lower boiling component. The latter was collected and distilled to give trans-*ethyl 2-cyanocyclohexylacetate*, b.p. 115–118°/0·25 mm. (Found: C, 67·70; H, 9·07. $C_{11}H_{17}NO_2$ requires: C, 67·66; H, 8·78%); IR spectrum (liquid film): 2240 (w), 1725 (s), 1452 (m), 1378 (m), 1167 (m), and 1027 cm^{-1} (m).

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