136. *The Determination of Dissociation Constants of Monobasic Acids. Part III. The Strengths of Some Cyano-acids.*

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Thermodynamic dissociation constants of some cyano-substituted carboxylic acids have been measured by a conductivity method, the extrapolation equation discussed in the preceding paper being used. The results are considered in relation to the structure of the cyano-acids and are correlated with existing data on the influence of substituents on acid strength. A connexion between the dipole moment of the substituent and the dissociation constant of the acid is proposed, which can be applied only when the influence of the substituents is purely inductive in nature and when the effect of free rotation of bonds need not be considered.

THE cyano-group has received comparatively little attention in studies of the effects of polar substituents on acid strengths, in spite of the fact that it is particularly interesting because of its halogenoid ·nature but *m*-directing influence in benzene substitution. The preparation of a number of cyano-substituted carboxylic acids is now described. In general, they are fairly easily hydrolysed to the corresponding amic acids, a tendency which might be an obstacle to the determination of their dissociation constants by the usual methods. These determinations have been carried out by measurement of conductivities of dilute aqueous solutions of the acids, and dissociation constants have been calculated by the extrapolation method (cf. preceding paper), which does not require the preparation of sodium salts. The range of acids has been limited by difficulties of preparation and purification, and the available data are summarised below, and discussed in three sections.

Acid.	$K \times 10^5$.	Acid.	$K \times 10^5$.
Cyanoacetic	342	*cyclo*Hexylcyanoacetic	430
β-Cyanopropionic	10·2	Dimethylcyanoacetic	380
γ-Cyano-*n*-butyric	3·66	*trans*-1-Cyano*cyclo*hexane-2-carboxylic	13·65

[The only previously recorded dissociation constant is that of cyanoacetic acid ($3·73 \times 10^{-3}$, Ostwald, *Z. physikal. Chem.*, 1889, **3**, 170; $3·63 \times 10^{-3}$, Wightman and Jones, *Amer. Chem. J.*, 1911, **46**, 56; $3·49 \times 10^{-3}$, Kendall, J., 1912, **101**, 1275, recalculated by MacInnes, *J. Amer. Chem. Soc.*, 1926, **48**, 2068; $3·36 \times 10^{-3}$, Saxton and Darken, *ibid.*, 1940, **62**, 847).]

ω-*Substituted* n-*Aliphatic Acids.*—For purposes of comparison, dissociation constants ($\times 10^5$) of terminally substituted acetic, propionic, and *n*-butyric acids are collected below. Since the absolute accuracy of these figures is not of importance, they are, unless otherwise stated, the " classical " values taken from Scudder, " The Electrical Conductivity and Ionization Constants of Organic Compounds," 1914.

R.	$CH_2R \cdot CO_2H$.	$CH_2R \cdot CH_2 \cdot CO_2H$.	$CH_2R \cdot CH_2 \cdot CH_2 \cdot CO_2H$.
H	1·753 (*a*)	1·336 (*b*)	1·50 (*b*)
F	213 (*c*)	—	—
Cl	139·7 (*d*)	10·1 (*e*)	3
Br	138	9·8	2·6
I	71	9·0	2·3
CN	342 (*f*)	10·2 (*f*)	3·66 (*f*)
CO$_2$H	149 (*g*)	6·41 (*g*)	4·53 (*g*)

References.—(*a*) Shedlovsky, *J. Amer. Chem. Soc.*, 1932, **54**, 1411; (*b*) Harned and Ehlers, *ibid.*, 1933, **55**, 2379; (*c*) Swarts, *Bull. Sci. Acad. roy. Belg.*, 1922, **8**, 343; (*d*) MacInnes, Shedlovsky, and Longsworth, *Chem. Rev.*, 1933, **13**, 29; (*e*) Dawson, Hall, and Key, J., 1928, 2844; (*f*) present paper; (*g*) Gane and Ingold, J., 1931, 2153.

Cyanoacetic acid is seen to be much stronger than the halogeno-acids. This might be attributed, at first sight, to the very powerful inductive effect of the CN group, which has a bond moment greatly exceeding those of C–Hal. This explanation does not hold, however, when interatomic distances are taken into account, since the primary moment in the cyano-acid is considerably farther away from the acidic hydrogen than in the other cases. The strength of β-cyanopropionic acid does not indicate any such predominance of inductive effect for the cyano-group. Quantitative correlations between dipole moments of substituents and ionisation constants have been developed (Waters, *Phil. Mag.*, 1929, **8**, 436; Smallwood, *J. Amer. Chem. Soc.*, 1932, **54**, 3048; Schwartzenbach and Egli, *Helv. Chim. Acta*, 1934, **17**, 1184; Schwartzenbach and Epprecht,

ibid., 1936, **19**, 493; Nathan and Watson, J., 1938, 890; Westheimer and Shookhoff, *J. Amer. Chem. Soc.*, 1939, **61**, 555, 1977, etc.), but a simple treatment, for comparative purposes only, is now suggested for acids which are closely similar in type. All such calculations require an assumption as to the location of the carboxylic hydrogen atom, and, as a simplifying approximation, it has been assigned to a position on the extension of the line joining the α- and the carboxylic carbon atom, 1·45 A. beyond the latter (Kirkwood and Westheimer, *J. Chem. Physics*, 1938, **6**, 506). The following dimensions have been used : covalent atomic radii, C, 0·77; F, 0·64; Cl, 0·99; Br, 1·14; I, 1·33 A.; CN bond length, 1·16 A.; and the tetrahedral angle of 109° 28'. The vector components of the field at the carboxylic hydrogen atom, due to the substituent dipole, $E_x = \mu(3\cos^2\theta - 1)/\varepsilon r^3$ and $E_y = \mu(3\sin\theta\cos\theta)/\varepsilon r^3$ (where μ is the moment of the primary dipole, θ the angle between the dipole axis and the line joining it to the hydrogen atom, r the length of this line, and ε the dielectric constant of the medium), parallel and perpendicular respectively to the dipole axis, have been resolved along the axis of the carboxyl group (cf. Groves and Sugden, J., 1937, 1992). The primary dipole is assumed to be dimensionless and situated midway between the parent atoms. Since we are concerned with the effect of the substitution of a group for hydrogen, the dipole is taken as equal in moment to that of the corresponding substituted methane and, because the calculations have no absolute significance, the dielectric constant of the medium has been taken as unity. The results are shown below.

X.	μ of CH_3X.	r, A.	θ.	E.	pK, calc.	pK, obs.	Δ.
F	1·81 (a)	2·32	53° 54'	0·197	2·70	2·67	0·03
Cl	1·87 (b)	2·43	50° 34'	0·190	2·77	2·85	−0·08
Br	1·80 (b)	2·48	49° 13'	0·177	2·91	2·86	0·05
I	1·64 (b)	2·54	47° 36'	0·153	3·16	3·15	0·01
CN	3·94 (b)	3·36	33° 59'	0·174	2·98	2·47	0·51

References. (a) Smyth and McAlpine, *J. Chem. Physics*, 1934, **2**, 499; (b) Groves and Sugden, J., 1937, 158.

The component of the dipole field along the carboxyl axis, in a direction to facilitate the ionisation of the hydrogen atom, is shown under E (col. 5). If the influence of the polar substituent on the strength of the acetic acid is solely electrostatic in origin, and if the component of the field in this single direction is alone significant, these figures indicate that cyanoacetic acid should be about equal in strength to bromoacetic acid. These assumptions are supported for the halogen acids in the following manner. The field is multiplied by the electronic charge and by a distance, d, in order to obtain a quantity with the dimensions of energy; application of the isotherm would then give ΔpK, defining, in the usual terms, the difference in strength between the unsubstituted and substituted acids. The converse calculation has been carried out for the halogeno-acids, d being calculated from the known values of ΔpK. The results for the fluoro-, chloro-, bromo-, and iodo-acids are 0·209, 0·197, 0·212, and 0·207 A., respectively. This quantity can have little real significance : it will depend inversely on the effective dielectric constant assumed for the medium and will, in effect, contain the various uncertainties associated with the problem. It is, however, of suitable magnitude for, and may be plausibly pictured as, a distance through which the carboxylic hydrogen atom must be withdrawn from the molecule before it can separate as a hydrion. The remarkable constancy of the value of d for the four acids leads to the tentative inference that the substitutional effects are in these cases predominantly electrostatic. A mean value of 0·206 A. for d leads to the calculated pK values shown in col. 6 of the foregoing table, and these may be compared with the known values in col. 7, the differences being shown in the last column. There must, of course, be general agreement in the case of the halogen acids, but it is noteworthy that the results are self-consistent and show no systematic deviations. Cyanoacetic acid, on the other hand, shows a very considerable discrepancy, and it is suggested that this acid is abnormally strong owing to the operation of a factor of a different kind. The same conclusion may be reached if internally transmitted inductive effects are considered ; the additional carbon atom interposed in the cyano-acid would reduce any such effect by a factor of the order of 0·02 (Waters, J., 1933, 1551), much more than sufficient to counterbalance the greater primary dipole.

A reason for this enhancement in strength can be found in the polarisability (or, possibly, mesomeric polarisation) of the nitrile group, N≡C–CH₂–CO₂H. There is no direct tautomeric path by which this can be transmitted to the carboxyl group, but it may be relayed inductively in the manner suggested by Dippy, Watson, and Williams (J., 1935, 346), and may be compared with the enhancement in strength found in vinylacetic acid ($K = 4\cdot48 \times 10^{-5}$; Ives, Linstead, and Riley, J., 1933, 561) and in phenylacetic acid ($K = 4\cdot88 \times 10^{-5}$; Dippy and Williams, J., 1934, 161) as compared with acetic acid ($K = 1\cdot753 \times 10^{-5}$). It may be noted that the ΔpK values in these two cases (0·41 and 0·44, respectively) are of the same order of magnitude as the difference between observed and calculated pK's for cyanoacetic acid (0·51).

Such an effect is considerably reduced when an additional methylene group is interposed (β-phenylpropionic acid, $K = 2\cdot19 \times 10^{-5}$, Dippy and Lewis, J., 1937, 1008; Δ$^\gamma$-pentenoic acid, $K = 2\cdot10 \times 10^{-5}$, Ives, Linstead, and Riley, *loc. cit.*; cf. propionic acid, $K = 1\cdot335 \times 10^{-5}$, Dippy, *loc. cit.*), and it is found that β-cyanopropionic acid is not significantly stronger than the β-halogenated acids. A similar calculation to the above has been applied to the propionic acids, assuming them to exist predominantly in the *trans*-configuration, and adopting a value for d of 0·328 A. The results are shown on p. 515. The cyano-acid is, if anything, slightly weaker than would be anticipated in this case.

X.	r, A.	θ.	E.	pK, calc.	pK, obs.	Δ.
Cl	3·68	23° 14'	0·0575	3·92	4·00	−0·08
Br	3·75	22° 47'	0·0529	3·99	4·01	−0·02
I	3·84	22° 14'	0·0455	4·12	4·05	0·07
CN	4·85	17° 26'	0·0599	3·88	3·99	−0·11

An analogy with the cyano-acids can be found in the dicarboxylic acids, the primary dissociation constants of which are included in the table on p. 513. Malonic acid (regarded as α-carboxyacetic acid) is relatively stronger, compared with the β-carboxylic acid (succinic), than would be anticipated from a purely inductive effect. This can clearly be seen from the ratio K_α/K_β, which, for the various substituted acids, has the values Cl, 15; Br, 14; I, 8; CN, 33; CO$_2$H, 23 : the two groups which are *m*-directing in benzene substitution have notably larger values of this ratio. This is all the more significant when it is remembered that the relative decrease in field strength at the ionisable hydrogen atom resulting from the intercalation of successive methylene groups is much less in these two cases than in the others, because the initial distance from the primary dipole in the α-acid is considerably greater. This factor would tend to reduce the difference in acid strength between the homologues and is, indeed, distinguishable in the slightly greater relative strengths of glutaric and γ-cyano-*n*-butyric acids (see p. 513).

The Effect of Alkyl Substitution.—Dimethylcyanoacetic acid is appreciably stronger than cyanoacetic acid, an unexpected result in view of the electron-release function of methyl groups, but in accordance with the Thorpe–Ingold valency deflexion hypothesis. If dimethyl substitution causes a decrease in the valency angle between the cyano- and the carboxy-group of the order of 2°, it can be shown that such an increase in strength would result. Recent work has shown, however, that such an explanation must be accepted with reserve (Westheimer and Shookhoff, *J. Amer. Chem. Soc.*, 1939, **61**, 555) and an alternative interpretation appears to merit consideration. Comparison can be made with the analogous pair of malonic acids : the four dissociation constants ($\times 10^5$) are : cyanoacetic, 342; dimethylcyanoacetic, 380; malonic, 149; dimethylmalonic, 68·3 : the effects of dimethyl substitution are opposite in the two cases. The polarisation of the cyano-group enhances acid strength in the manner already suggested, but it also promotes lability of the methylene hydrogen atoms, which are well known to be abnormally reactive. It may be suggested that the cyanoacetic acid molecule is degenerate, involving the resonance forms (I), (II), and (III), of which (III) is likely to be more significant than (II), and clearly leads to a distribution of charges unfavourable to the

(I.) (II.) (III.)
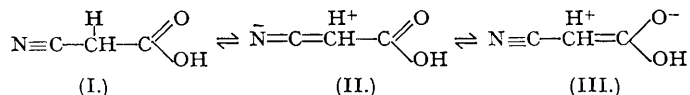
ionisation of the carboxylic hydrogen. It might be said, alternatively, that the methylene activation has a depressing effect on acid strength because it partly " short circuits " the influence of the cyano-group in promoting ionisation. In dimethylcyanoacetic acid, however, such activation, and the resonance of which it is the result, cannot occur, and the full effect of the cyano-group is transmitted to the carboxylic hydrogen atom. The situation is not quite the same in the case of the malonic acids because the resonance state must be symmetrical and any unfavourable charge which develops must be distributed between two carboxyl groups. The influence of any dipole must be self-cancelling because of the statistical factor; either one group or the other may ionise. The strength of malonic acid is therefore not appreciably depressed by resonance, and dimethyl substitution produces the expected decrease in strength because of the electron-releasing properties of the methyl groups.

The greater strength of *cyclo*hexylcyanoacetic acid than of cyanoacetic (430 $\times$ 10^{-5} and 342 $\times$ 10^{-5}, respectively) is more marked, and may be associated with the introduction of a large polarisable group : it is paralleled by the greater strength of *cyclo*hexylacetic than of acetic acid (2·36 $\times$ 10^{-5}, Zelinsky and Izgarysev, *J. Russ. Phys. Chem. Soc.*, 1908, **40**, 1379, and 1·753 $\times$ 10^{-5}, respectively). Comparisons of this kind, however, between acids differing considerably in structure and dimensions may be invalidated by differences in entropy of ionisation (cf. Hammett, *J. Chem. Physics*, 1936, **4**, 613) ; *e.g.*, the large increase in the size of the anion in this case may cause a smaller decrease in entropy owing to orientation of water molecules in solution. Other steric factors may also be significant (cf. Brown and Bartholomay, *ibid.*, 1943, **11**, 43). All discussions of minor differences in acid strength are subject to these uncertainties.

trans-1-*Cyano*cyclo*hexane*-2-*carboxylic Acid.*—Preparative difficulties have precluded the comparison of *cis*- and *trans*-modifications of this acid with each other and with the rigid-ring *cyclo*pentane analogues. In one of the possible strainless forms of the *trans*-acid, it can be shown that the N≡C—ĊH—ĊH—CO$_2$H skeleton will lie in one plane in the *trans*-configuration; it is considered that dipole interaction will strongly favour this particular strainless form. Applying the method of calculation already described, and using the same value for the distance d as for the substituted propionic acids and $K = 1·28 \times 10^{-5}$ for the corresponding unsubstituted acid (hexahydrobenzoic acid, Scudder, *loc. cit.*), we obtain p$K = 3·90$. This compares very well with the observed value of 3·86, and this agreement may be taken as supporting the predominant *trans*-configuration of the propionic acids : a *cis*-configuration would involve a very great increase in strength of the cyano-acid. A comparison with the dicarboxylic acids may be made in confirmation of this conclusion. The primary dissociation constant of succinic acid (6·41 $\times$ 10^{-5}; Gane and Ingold, *loc. cit.*) is much closer to that of *trans*-

hexahydrophthalic acid ($6 \cdot 61 \times 10^{-5}$) than of the *cis*-acid ($4 \cdot 57 \times 10^{-5}$; Kuhn and Wassermann, *Helv. Chim. Acta*, 1928, **11**, 50). Mills (*Reports Inst. Solvay*, 1931) has suggested that succinic acid has the *trans*-form in its equilibrium conformation, and it is to be expected that it will be simulated in this respect by its half-nitrile.

EXPERIMENTAL.

Conductivity Measurements.—The apparatus and method were similar to those described by Ives and Riley (J., 1931, 1998). All measurements were made at 25°, and all the solutions were prepared with water of specific conductivity $0 \cdot 15$—$0 \cdot 30 \times 10^{-6}$ ohm^{-1}, obtained from a Stuart and Wormwell still (J., 1930, 85). Suitable precautions were adopted to prevent the uptake of moisture by hygroscopic solutes during weighing. At least two series of measurements were carried out with each acid, samples being either from independent preparations or from successive crystallisations. In all cases one of the measured solutions was kept in the conductivity cell overnight in order to detect any solvolytic reaction which might have invalidated the treatment of the results. No such reaction was found in any case. The results are tabulated below, data for one acid being given in full in order to indicate the degree of concordance obtained, and Λ_0 values for each series of runs of the other acids.

Cyanoacetic Acid.

$C \times 10^4$.	Λ.	$K \times 10^5$.	$C \times 10^4$.	Λ.	$K \times 10^5$.	$C \times 10^4$.	Λ.	$K \times 10^5$.
9·483	316·75	342	10·427	310·83	340	13·709	297·36	343
7·520	327·31	342	7·925	323·92	342	10·166	312·82	343
5·796	337·71	342	6·104	334·65	341	7·610	326·18	343
4·488	346·77	343	4·578	344·46	337	5·891	336·57	344
3·182	356·65	341	3·562	352·00	335	4·281	347·61	344
0	388·7	—	2·712	359·46	342	3·232	355·27	340
			1·972	366·22	346	2·346	362·99	343
			0	387·5	—	1·717	368·83	344
						0	387·8	—

β-Cyanopropionic acid : Λ_0, 381·1, 380·6. γ-Cyano-*n*-butyric acid : Λ_0, 377·7, 378·1. Dimethylcyanoacetic acid : Λ_0, 380·9, 381·6. *cyclo*Hexylcyanoacetic acid : Λ_0, 371·3, 370·7. *trans*-1-Cyano*cyclo*hexane-2-carboxylic acid : Λ_0, 375·9, 375·3.

Preparation of Materials.—Cyanoacetic acid. Prepared by Phelps and Tillotson's method (*Amer. J. Sci.*, 1908, **26**, 275) and repeatedly crystallised from sodium-dried benzene and light petroleum; m. p. 68—68·5° (Letch and Linstead, J., 1932, 450, give 68°) (Found : C, 42·3; H, 3·4. Calc. for $C_3H_3O_2N$: C, 42·4; H, 3·5%).

β-Cyanopropionic acid. Treatment of sodium β-chloropropionate with potassium cyanide in aqueous solution yielded only succinamic acid (m. p. 153—154°). The cyano-ester was therefore prepared by heating β-chloropropionic ester (25 g.) with potassium cyanide (20 g.) in alcohol (100 c.c.) on the steam-bath for 6 hours. Working up by the usual methods gave 18·5 g. of vacuum-distilled product, b. p. 104—106°/11 mm., $d_4^{20°}$ 1·0359, $n_D^{20°}$ 1·4233 (Found : C, 56·35; H, 7·1. Calc. for $C_6H_9O_2N$: C, 57·0; H, 7·1%). The ester (25 g.) was hydrolysed by 3 days' standing at room temperature with potassium hydroxide (20 g.) in methanol (200 c.c.). The potassium salt was isolated, washed with dry ether, and decomposed in dry benzene by saturation with dry hydrogen chloride (mechanical stirring). Potassium chloride was removed, the benzene evaporated under reduced pressure, and the resulting β-cyanopropionic acid repeatedly crystallised from dry chloroform and light petroleum; m. p. 50—51° (Dakin, *Biochem. J.*, 1917, **11**, 84, gives 48—50°) (Found : C, 48·2; H, 5·2. Calc. for $C_4H_5O_2N$: C, 48·5; H, 5·05%). The presence of water led to hydrolysis of the cyano-ester to succinic acid.

*γ-Cyano-*n*-butyric acid.* Vinylacetic acid (Linstead, Noble, and Boorman J., 1933, 560) was treated with dry hydrogen bromide in 4 vols. of dry toluene (Boorman, Linstead, and Rydon, J., 1933, 560), giving an almost theoretical yield of γ-bromo-*n*-butyric acid, m. p. 32°. This acid was esterified (Wohlgemuth, *Ann. Chim.*, 1914, **2**, 298), and the ester (55 g.), b. p. 88—90°/14 mm., dissolved in alcohol (300 c.c.) and refluxed with potassium cyanide (27 g.) for 48 hours. The product was worked up in the manner already described, and ethyl γ-cyanobutyrate (32 g.) obtained by vacuum distillation, b. p. 120—122°/18 mm. Hydrolysis, by standing with 50% excess of methyl-alcoholic potash at room temperature, yielded, by the usual procedure, γ-cyano-*n*-butyric acid (10 g.), which was recrystallised several times from benzene–light petroleum; m. p. 52—53° (Dieckmann, *Ber.*, 1900, **33**, 588, gives m. p. *ca.* 45°) (Found : C, 53·0; H, 6·3. Calc. for $C_5H_7O_2N$: C, 53·1; H, 6·2%).

Dimethylcyanoacetic acid. The corresponding ester, prepared from sodiocyanoacetic ester and methyl iodide (Hessler, *J. Amer. Chem. Soc.*, 1913, **35**, 990), was purified from monomethyl ester by partial hydrolysis with dilute aqueous sodium hydroxide and vacuum distilled; b. p. 58—60°/1·5—2 mm. (Found : C, 59·4; H, 7·8. Calc. for $C_7H_{11}O_2N$: C, 59·5; H, 7·8%). Hydrolysis with methyl-alcoholic potash and purification in the usual manner yielded dimethylcyanoacetic acid, m. p. 60—61° (Hessler, *J. Amer. Chem. Soc.*, *loc. cit.*, gives 57°; Böhm, *Monatsh.*, 1906, **27**, 952, gives 56—57°) (Found : C, 52·95; H, 6·4. Calc. for $C_5H_7O_2N$: C, 53·1; H, 6·2%).

cycloHexylcyanoacetic acid. *cyclo*Hexylidenecyanoacetic ester, b. p. 153°/15 mm. (Haworth, Harding, and Perkin, J., 1908, **93**, 1943), was reduced in ethereal solution with aluminium amalgam (Vogel, J., 1927, 597), yielding *cyclo*-hexylcyanoacetic ester, b. p. 156°/12 mm., which was hydrolysed at room temperature with methyl-alcoholic potash. The acid was repeatedly recrystallised from benzene–light petroleum; m. p. 81—82° (Found : C, 64·6; H, 7·8. Calc. for $C_9H_{13}O_2N$: C, 64·7; H, 7·8%).

The hexahydrophthalic acids and their half-nitriles. The preparation of *cis*- and *trans*-1-cyano*cyclo*hexane-2-carboxylic acids involved the production of the corresponding hexahydrophthalic acids. The following series of reactions was explored.

(1) Ethyl 1-bromo*cyclo*hexane-2-carboxylate, b. p. 132—136°/14 mm., prepared from *cyclo*hexanone cyanohydrin via Δ¹-tetrahydrobenzonitrile and addition of hydrogen bromide to Δ¹-tetrahydrobenzoic acid, merely lost hydrogen bromide on treatment with potassium cyanide.

(2) 1 : 2-Dibromo*cyclo*hexane, b. p. 105°/20 mm., could not be converted into the dinitrile with potassium or cuprous cyanide under any conditions, including heating in a sealed tube at 200°.

(3) Ethyl *cyclo*hexanone-2-carboxylate (Kotz, *Annalen*, 1906, **350**, 210; 1908, **358**, 198) was converted into the cyanohydrin, b. p. 168—170°/30 mm., m. p. 53—54°, $d_4^{25°}$ 1·1053, $n_D^{25°}$ 1·4637 (supercooled liquid in each case) (Found : C, 61·0; H, 7·8. $C_{10}H_{15}O_3N$ requires C, 60·9; H, 7·6%), and this, in turn, into *ethyl 1-cyanocyclohexene-2-carboxylate*, b. p. 149—151°/8 mm.; $d_4^{25°}$ 1·0677, $n_D^{25°}$ 1·4843 (Found : C, 66·7; H, 7·1. $C_{10}H_{13}O_2N$ requires C, 67·0; H, 7·3%), but this could not be reduced either by hydrogenation in the presence of Adams's catalyst or by aluminium amalgam.

(4) Δ^1-Tetrahydrobenzonitrile (22 g.), potassium cyanide (53 g.), alcohol (200 c.c.), water (100 c.c.), and concentrated hydrochloric acid (20 c.c.) were heated in a pressure bottle at 100° for 4 hours. After cooling, the alcohol was removed, and the solution extracted with ether, the aqueous layer being set aside. The extract, washed with concentrated calcium chloride solution and dried, yielded 1 : 2-*dicyano*cyclo*hexane* (10 g.), b. p. 184—188°/25 mm., m. p. 42° (Found : C, 71·2; H, 7·6. $C_8H_{10}N_2$ requires C, 71·5; H, 7·6%), hydrolysed to *trans*-hexahydrophthalic acid, m. p. and mixed m. p. 220°. The aqueous layer, on acidification, removal of hydrogen cyanide, and ether extraction, gave a small amount of *cis*-hexahydrophthalic acid, m. p. and mixed m. p. 189°

trans-Hexahydrophthaloyl *chloride* (20 g.), b. p. 145—146°/20 mm. (Found : Cl, 33·9. $C_8H_{10}O_2Cl_2$ requires Cl, 34·0%), prepared by heating the acid with phosphorus pentachloride, was slowly added to ammonia (d 0·88; 200 c.c.); a vigorous reaction ensued and the mixture was left overnight. Excess ammonia was removed, and the solution concentrated under reduced pressure. Acidification and ether extraction, followed by working up in the usual way, provided trans-1-*cyano*cyclo*hexane-2-carboxylic acid* (10 g.), which was crystallised from aqueous alcohol; m. p. 128—129° (Found : C, 62·7; H, 7·3; equiv., by titration, 153. $C_8H_{11}O_2N$ requires C, 62·7; H, 7·2%; equiv., 153). Acid or alkaline hydrolysis yielded *trans*-hexahydrophthalic acid.

Similar treatment of *cis*-hexahydrophthalic acid afforded, not the *cis*-, but the *trans*-dichloride [identity of b. p., production of same *trans*-dianilide (m. p. and mixed m. p. 301°), and of same cyano-acid as the above on treatment with ammonia]. Treatment of the *cis*-acid in ethereal solution with phosphorus pentachloride gave the *cis*-acid chloride. This could not be isolated by distillation, but its production was demonstrated by formation of the *cis*-anilide, m. p. 234° after recrystallisation from dilute acetic acid, and thence of the phenylimide, m. p. 130°, by refluxing for several hours with 80% acetic acid. Stoermer and Steinbeck (*Ber.*, 1932, **65**, 417) give m. p.'s 234° and 132°, respectively, and state that 80% acetic acid has no action on the *trans*-dianilide. The action of ammonia (d 0·88) on the *cis*-chloride yielded only *cis*-hexahydrophthalamic acid, m. p. 168—170°. Use of thionyl chloride instead of phosphorus pentachloride led to the same result.

(5) Ethyl cyclo*hexanone-2-carboxylate cyanohydrin* (10 g.) in the minimum of benzene was slowly added to phosphorus pentachloride (11 g.), cooled in ice. After 2 hours, the mixture was poured into water and extracted with ether. The extract, on being worked up in the usual manner, yielded *ethyl* 1-*chloro*-1-*cyano*cyclo*hexane-2-carboxylate*, which crystallised from aqueous alcohol in fine silky needles, m. p. 87—88° (Found : Cl, 17·2. $C_{10}H_{14}O_2NCl$ requires Cl, 17·5%). This ester (5 g.) in 50% acetic acid (50 g.) was treated slowly (4—5 hrs.) with zinc dust (2·5 g.), and left on the steam-bath overnight. Working up in the usual manner afforded ethyl *trans*-1-*cyano*cyclo*hexane-2-carboxylate* (3 g.), b. p. 140°/9 mm., hydrolysed to *trans*-hexahydrophthalic acid, m. p. and mixed m. p. 218°, but as this ester was impure and the yield small, the cyano-acid for the conductivity measurements was obtained by method (4).