# ELECTRICAL POLARIZATION OF TETRAMETHYLCYCLOBUTANES

F. LAUTENSCHLAEGER AND GEORGE F WRIGHT Department of Chemistry, University of Toronto, Toronto, Ontario Received October 31, 1962

### ABSTRACT

Because the postulated non-planarity of *sym*-tetramethylcyclobutanedione is based on a small value of electrical polarization, the *cis*- and *trans*-2,2,4,4-tetramethylcyclobutane-1,3-diisocyanides have been prepared and stereospecifically rearranged to the analogous dicyanides. These substances show sufficiently large polarizations that the explanation of ring non-planarity is substantiated. Calculations in terms of the expected and observed dipole moments show that the ring deviates 20-30° from planarity. Although this non-planarity is not static, according to consideration of the cis geoisomers it would appear that one conformation is more prevalent than any others.

Although many investigators have concluded that their cyclobutanes existed in planar ring conformation (1-7) there have been others who found evidence for non-planarity on the basis of infrared and Raman absorption (8) (perfluorocyclobutane) and of electron diffraction with perfluorocyclobutane and methylcyclobutane (9) as well as with unsubstituted cyclobutane (10) and 1,3-dimethylenecyclobutane (11).

Electrical polarization studies also have indicated non-planarity. An apparent moment which was increased by higher temperature was found for  $1-\uparrow-2-\uparrow-3-\downarrow-4-\downarrow$ -tetraphenylcyclobutane. Also the difference between the total polarization of 2,2,4,4-tetramethylcyclobutane-1,3-dione and its electronic polarization could no longer be attributed to abnormally high atom polarization, as Coop and Sutton had done (3), after the distortion polarization ( $P_{E+A}$ ) of the substance was measured (12) and was found to be only 0.6 cc higher than the calculated electronic polarization. An apparent moment of 0.8 D had then to be assigned to tetramethylcyclobutanedione. Assuming the group moment of the carbonyl group to be 2.8 D the apparent deviation from ring planarity thus is calculated to be 20°, a value conforming roughly with earlier postulations (7, 9).

We have confirmed this evidence for non-planarity by preparation of the 1,3-diisocyanides and the 1,3-dicyanides of 2,2,4,4-tetramethylcyclobutane. These compounds were prepared from the geoisomeric diamines, I, which recently have been made available (13), but the reaction of Hofmann was not satisfactory for conversion of the amines to the isocyanides. However, Ugi's method (16) involving formamides with phosphorus oxychloride and pyridine gives good conversions of the *cis*- and *trans*-tetramethycyclobutane-1,3-diformamides, II, to the diisocyanides, III. Although an efficient method for separation of the geoisomeric amines has not yet been evolved the mixture obtained by formylation may easily be separated into *cis*- and *trans*-II by crystallization.

The diisocyanides III (cis and trans) are reconvertible to the corresponding formamides II by treatment with acetic acid. Also, they form cis and trans dibromides, VI. Of greater interest is the ease with which they are rearranged stereospecifically in good yield to the cis and trans cyanides, IV, by rapid heating at temperatures of about 310°. This reaction is most welcome, because any doubt about the linearity of the isocyanide group (and linearity is a necessary condition for unequivocal interpretation of the observed electrical polarization) is allayed by the well-known linearity of the cyanide group. The results of electrical polarization measurements (Table I) confirm that the isocyanide group is

Canadian Journal of Chemistry. Volume 41 (1963)

Substance	Temp. (C°)	$\frac{\delta \epsilon}{\delta \omega}$	$rac{\delta  \overline{V}}{\delta \omega}$	ε b or d	<del>د</del> extrap.	$\overline{V}$ b or d	$\overline{V}$ extrap.	$P_{T}$ solute	$P_{\mathrm{D}}$	<b></b> (D)
cis-TMCB-	20 b	12.6	-0.123	2.2825	2.283	1.13795	1.13780	429	46.4†	4.26
1,3-dicyanide*										
trans-TMCB-	20 Ь	1.05	-0.10	2.2825	2.2822	1.13805	1.13810	82	$50.2^{+}$	1.23
1,3-dicyanide										
cis-TMCB-	20 b	9.45	-0.05	2.2822	2.2823	1.13805	1.13805	339	$52.1^{+}$	3.68
1.3-diisocvanide	40 b	8.36	-0.05	2.2431	2.2430	1.16647	1.16640	317	$52.1^{+}$	3.66
trans-TMCB-	20 b	0.88	-0.05	2.2822	2.2823	1.13805	1.13805	79.6	47.3	1.24
1.3-diisocvanide	$\overline{35}$ $\tilde{b}$							76.9	47.3	1.22
	20 đ	1.35	-0.14	2,2202	2.2202	0.96745	0.96735	87.5	47.3	1.38
TMCB-1-isocvanide	20 h	9 92	+0.068	2 2828	2 2824	1 13813	1 13811	303	43 Ot	3.52
1-Keto-TMCB	20 5	6 18	+0.055	2 2828	2 2845	1 13881	1 13802	203	37 08	2.81
TMCB dione	20 b	0.22	-0.03	2 2837	2 2838	1 13768	1 13768	52 4	38.3	$\bar{0}$ 82
Three dione	30 b	0 18	-0.05	2 2625	2 2624	1 15207	1 15196	50 7	38.3	0.78
	40 b	0.13	-0.06	2 2418	2 2410	1 16686	1 16682	48 0	38.3	0 73
cis-TMCB-1 3-diol	20 4	5 04	$\pm 0.00$	2 2255	2 2256	0.06770	0.06770	160	40	2 39
trans-TMCB-13-diol	20 d	3 79	$\pm 0.01$	2.2200	2.2200	0.96770	0.96770	130	40	2 10
h Chlorobongonitrilo	20 0	5 79	-70.00	2.2200	2.2200	1 12910	1 12011	100	22 6	2.10
p-Cillorobenzoniti ne	20 D	0.10	-0.30	4.4040	2.2020	0.06740	0.06749	104	22 6	2.04
5 Tolumitailo	20 U 20 L	10.00		· 2.2100	2.2100	1 19014	1 12020	102	25 0	4 47
p-rountenie	20 D	19.20	-0.13	4.4820	2.2819	1,10014	1,10820	400	00.0 95 0	4.47
h Dilagana share a	20 d	44.90	+0.05	2.2184	4.2184	0.90742	0.90742	412	00.0 41.4	4.00
<i>p</i> -Diisocyanobenzene	20 D	0.62	-0.207	4.4825	4.2825	1.13812	1.13812	50.4	41.4	0.07

TABLE I Electrical polarization of solutions in benzene (b) or dioxane (d)

\*TMCB refers to "2,2,4,4-tetramethylcyclobutane". †See Table II. Evaluated from  $d_{2^{20}} = 1.428$  and  $n_D^{20} = 0.821$ . §Evaluated from  $d_{4^{20}} = 1.4143$  and  $n_D^{20} = 0.824$ .

CANADIAN JOURNAL

OF

CHEMISTRY.

VOL. 41, 1963



linear, at least in cyclobutanes, since the observed moments of *trans*-III and *trans*-IV are almost identical.

The rearrangement of isocyanides to cyanides at elevated temperatures has long been known (17–19). Our reactions are noteworthy only because the behavior is not in accord with that observed by Wade (20). This worker found that thoroughly dried methyl and ethyl isocyanide did not rearrange during 2 hours at 250° although the moist substances reacted rapidly below 184°. Likewise impure phenylisocyanide in his hands rearranged rapidly whereas the pure compound resinified without a trace of rearrangement.

Our reaction conditions differ from Wade's in respect of our higher temperature (310° because we found that temperatures of 220–240° for 8–10 hours led to extensive side reaction) but our rearrangements were complete within 3 minutes despite the fact that our isocyanides were dried and freed from amine at least as rigorously as were Wade's. Consequently we cannot for our reaction accept Wade's postulation that the contaminating parent amine acts as catalyst even though his suggestion would be compatible with our observation of stereospecificity:

$$\phi - N \equiv C + H_2 N - \phi \rightarrow H - C - NH - \phi$$

$$\| N - \phi$$

$$\phi - C \equiv N + H_2 N - \phi \leftarrow \phi - C - NH - \phi$$

$$\| N - H$$

865

Certainly our stereospecificity precludes the possibility that the isocyanide-cyanide rearrangement is acid catalyzed because the cyclobutane ring system is amenable to protonic isomerization. This catalyzed interconversion of stereoisomers was demonstrated for norpinic acid (21) and has also been observed during our acid hydrolysis of tetramethylcyclobutanedicyanide, IV, cis or trans, to the same equilibrium mixture of dicarboxylic acids, V.

The dipole moments of many aliphatic nitriles have been determined (22). On the other hand moment data for aliphatic isocyanides are sparse and none includes the cyclobutane ring. For this reason it seemed advisable to prepare 2,2,4,4-tetramethylcyclobutylisocyanide, XII. To this end 2,2,4,4-tetramethylcyclobutanone VII was prepared in low yield (together with 1,1,3,3-tetramethylcyclobutane) by the method of Herzog (23) and then was converted to the oxime VIII. Reduction with hydrogen and nickel gave the amine, X, but lithium aluminum hydride produced a secondary amine. This product of reductive rearrangement must evidently be 2,2,4,4-tetramethylpyrrolidine, IX. The formamide XI, which was prepared with ease from the amine X, was converted in good yield to the isocyanide, XII, by the method of Ugi and Meyr. The moment of XII, 3.5 D, is in reasonable agreement with values found for other aliphatic isocyanides (except methyl isocyanide) (22). Assuming that the C—H moment, which must be added algebraically, is directionally negative toward hydrogen (22), the group moment (in benzene) for the isocyano group is 3.8 D. Upon the same assumption (C  $\rightarrow$  H), the cyano group has essentially the same moment (3.8 D).



One might expect from similarity in group moment that the moments of the tetramethylcyclobutane-dicyanides and -diisocyanides would be nearly identical. As may be seen in Table I the moments of the trans isomers are the same (1.23 and 1.24 D) within experimental error. Of interest is the fact that the values are not zero; i.e., the groups do not mutually cancel one another. It is evident that the *trans*-tetramethylcyclobutanedicyanide and -diisocyanide present some asymmetry to the external electric field; they are dipolar.

The alternative interpretation (in which the excess of total polarization over that which may be assigned as electronic polarization is due to atom polarization,  $P_{\rm A}$ ) is unrealistic. This is apparent in view of our measurements from which the distortion polarization can

be calculated according to the method reported previously (12). These values are shown in Table II. Although a correlation between molecular geometry and atom polarization

				$MR_{D}^{*}$			
Substance	<i>d</i> 4 <sup>20</sup>	ε	$P_{\mathbf{E}+\mathbf{A}}$	Vogel c-aliphatic	Vogel c-aromatic	Eisenlohr	
trans-TMCB-	1.067	2.48	50.2	46.4		46.3	
1,3-dicyanide† cis-TMCB- 1.3-dicyanide	1.060	2.31	46.4	46.4		46.3	
trans-TMCB-	1.051	2.33	47.3	47.8		48.1	
<i>cis</i> -TMCB-	1.056	2.54	52.1	47.8	·	48.1	
Terephthalonitrile	1.280	2.94	39.4	35.4	35.1	31.1	
p-Chlorobenzonitrile	1.511	2.75	33.6	35.7	35.5	35.1	
<i>p</i> -Diisocyanobenzene	1.048	<b>2.54</b>	41.4	33.8	33.5	34.6	

TABLE II		
Electrical polarization of	pelleted	solids

tion values for —N≡C are unknown a group refraction (Eisenlohr atom, 6.10 cc or from np<sup>20</sup> and d₄<sup>20</sup> of cyclohexane and tetramethylcyclobutane versus their analogo been calculated r —C≡N the Eisenlohr value is 5.46 cc and the Vogel value is 4.82 cc. †TMCB refers to "2,2,4,4-tetramethylcyclobutane".

is not at present discernible it is at least apparent that  $P_A$  is not large (0-2 cc per nitrile or isonitrile group). In view of a general tendency to disregard our earlier determinations of distortion polarization which lead to assignment of orientation polarizations to benzoquinone (24), diphenylmercury (25), and tetramethylcyclobutanedione (12) it is satisfying that the high moment values for the dicyanides IV and the diisocyanides III do not depend very much on the spread of  $P_{E+A}$  values shown in Table II.

Since the measured dipole moments of the tetramethylcyclobutane-dinitrile and -diisonitrile are not zero the cyclobutane ring cannot be rigidly planar. It remains to ascertain the mode and the magnitude of this non-planarity. Evaluation of this magnitude does in general require a vectorial analysis which depends upon the angular distribution of hydrogen and cyano (or isocyano) substituents about the atom to which they are bound, but there is no fixed value for their angular distribution. Referring to Fig. 1 Friedlander



and Robertson (26) found in 2,2,4,4-tetramethylcyclobutanedione that  $\theta$  was 111° while Lemaire and Livingston (7) called  $\theta$  107–112° in octofluorocyclobutane. The same authors (9) assigned to  $\theta$  in methylcyclobutane a value of 100°. There is then a choice for  $\alpha$  of 125° or 130°.

However, the vectorial analyses for the trans isomers do not involve the angle  $\alpha$  if (as seems reasonable) the deformation from planarity is symmetrical. Reference to Fig. 2



shows by consideration of the congruent triangles which include the angles  $2\pi -\beta$ ,  $\gamma$ ,  $\alpha$  and the angles  $2\pi -\delta$ ,  $\gamma$ ,  $\alpha$  respectively that  $\delta = \beta$ . Therefore, the resultant moment depends only on the group moments and the dihedral angle  $\beta$ , that is,

$$\mu_{\rm res}^2 = (1.24)^2 = 2m^2 + 2m^2 \cos \beta,$$

where m = 3.8 Debye = group moment of cyanide or isocyanide, the moment contribution of the hydrogens being neglected.

The existence of a moment for the trans isomers of III and IV precludes the fixed planar structure XII in favor of the non-planar XIII. If XIII were fixed then  $\beta$  is 162°



for both the cyanide and the isocyanide. Alternatively one may consider an oscillating "structure" in which XII and XIII partake equally. Then the resultant (observed) moment,  $\mu_{res}$ , may be used to ascertain the moment of conformer XIII:

	$\mu_{\rm res}^2 = n_{\rm XII} \mu_{\rm XII}^2 + n_{\rm XIII} \mu_{\rm XIII}^2,$
where	$n_{\rm XII} = n_{\rm XIII} = 1/2;$
then	$2\mu_{\rm res}^2 = \mu_{\rm XII}^2 + \mu_{\rm XIII}^2$ ;
but since	$\mu_{\rm XII}^2 = 0,$
	$u_{\rm max} = \sqrt{(2u_{\rm max}^2)}$

So if  $\mu_{res}$  for *trans*-III or -IV = 1.24 D then  $\mu_{XIII} = 1.76$  D. Similarly if  $\mu_{res}$  for tetramethylcyclobutanedione = 0.8 D then  $\mu$  for the non-planar conformer = 1.26 D.

A graph may be constructed from calculations of expected moment at various  $\beta$  angles for 1,3-disubstituted tetramethylcyclobutane using a group moment of 3.8 D for cyano and for isocyano in benzene. A similar graph has been constructed for cyclobutanedione using a group moment (benzene solution) of 3.1 D (2.8+0.3) for keto. For an oscillating "structure" where  $\mu_{XIII} = 1.76$  D the angle  $\beta$  may be interpolated, 152° for the diisocyanide III and 152° for the dicyanide IV. An oscillating "structure" for 2,2,4,4-tetramethylcyclobutanedione ( $\mu_{obs}$ , 0.8 D) would have  $\beta = 156°$  in contrast to a  $\beta$  angle of 165° for a rigid non-planar structure.

We do not attach any significance to the relatively narrow range (4°) between the values derived from the  $\beta$  vs. moment graphs for the trans dicyanide and diisocyanide on the one hand and the diketone on the other. These values depend on the choice of group moment that is chosen for a substituent. Although the choice of 3.1 D for carbonyl in the dione is not completely arbitrary, being derived from the observed moment of 2,2,4,4-tetramethylcyclobutanone, there is no certainty that this moment is applicable. The carbonyl absorption of the monoketone in potassium bromide occurs strongly at 1770 cm<sup>-1</sup>, in the same range and extent that does 3-hydroxy-2,2,4,4-tetramethylcyclobutanone (1780 cm<sup>-1</sup> in chloroform) (27). These high frequencies are comparable with that found (28) for cyclobutanone. On the other hand the absorption of the dione carbonyls (potassium bromide) is split into two strong bands at 1725 and 1750 cm<sup>-1</sup>, which indicates a marked difference from carbonyl in the monoketone.

It should be emphasized that the deviations from ring planarity as exemplified by angle  $\beta$  are not to be construed as absolute values because solvent effects will contribute to the apparent moment. A real moment may be estimated only after apparent moments have been found in a number of solvents (24). The contrast in the present study ( $\mu = 1.24$  D in benzene versus 1.38 D in dioxane for trans diisonitrile III) is not sufficiently diverse for choice of a real dipole moment.

The electrical polarization data for the trans dicyanide IV and diisocyanide III do not permit a choice of rigid versus oscillating "structure" but additional information about 2,2,4,4-tetramethylcyclobutanedione favors the oscillating "structure". The nuclear magnetic resonance spectrum of this dione ought to show a difference in methyl-hydrogen environments if the substance were rigidly non-planar. On the other hand, it would display a single hydrogen-atom absorption either if the substance were rigidly planar or alternatively if it were oscillating at a rate greater than the several hundred cycles per second which is involved in the measurement of n.m.r. Since the rigidly planar structure is excluded by the existence of a dipole moment for *trans*-III and -IV it would appear that these molecules are oscillating at a rate between 200 and 10<sup>6</sup> cycles/sec in view of the single peak which we have observed as the n.m.r. spectrum. The more rapid of these rate limits is favored by the low-temperature coefficient of moment (Table I) found for the diisonitriles and the dione.

Whereas the angle ( $\alpha$ ) which the cyano or isocyano group forms with the tetramethylcyclobutane ring is inconsequential in respect of trans geoisomeric configurations, it becomes crucial in consideration of cis isomers. The choice of  $\alpha = 125^{\circ}$  will be used in the following calculations.



The three conformers to be considered for the cis isomers are shown as XIV, XV, and XVI. The angle of vector interaction in XV is obvious (70°) while that in XIV is

$$\gamma/2 + 55 + (180 - \beta/2) = 180$$
  
 $\beta = \gamma + 110$ 

and that in XVI is

$$\gamma/2 + \beta/2 + 55 = 180$$
  
 $\beta = 250 - \gamma.$ 

A set of resultant moments using  $\mu_{-CN}$  and  $\mu_{-NC}$  of 3.8 D for different  $\beta$  values has been calculated for XIV and XVI and is shown in Fig. 3. The intersection of these two at 180° marks the calculated moment of the planar conformer XV.



From Fig. 3 it may be concluded that conformation XV with calculated resultant moment of 6.2 D cannot alone represent the *cis*-2,2,4,4-tetramethylcyclobutane-1,3dicyanide of observed moment 4.26 D in benzene at 20°. It may be seen that if XVI were the sole conformer then  $\beta$  would be 138° but that XIV would have  $\mu = 4.26$  D only if  $\beta$  were 222°, i.e., if it were XVI. Finally, an oscillating species comprised of XVI, XIV, and XV in proportion 1:1:2 could according to the dotted line of Fig. 3 have a resultant moment of 4.26 D only if  $\beta$  were 87°, which is absurd. It is evident then that XVI must be grossly preponderant in order to account for the observed moment. It may be noted that XVI is the equatorial conformer.

Exactly the same analysis for the cis diisocyanide shows that conformer XV (dotted line at 180°) would have a moment (6.2 D) much larger than that observed (3.68 D) for *cis*-III in benzene at 20°. This observed moment would be explained by conformer XVI alone if  $\beta$  were 129° but not by XIV alone unless  $\beta$  were 231°, i.e., identical with XVI. As before, a 1:1:2 oscillating mixture of XIV, XVI, and XV would lead to an absurdly small  $\beta$  angle. It would seem that *cis*-tetramethylcyclobutane-1,3-diisocyanide (III) also exists preponderantly as the equatorial conformer XVI.

Of course any contribution from conformer XIV would require that  $\beta$  were smaller than the 141° and 145° attributed to the geometry of the diisocyanide and the dicyanide of conformation XVI (Fig. 3), but this further deviation from 180° (planarity) required by a dynamic molecule should not be taken too seriously. If in the calculations outlined above for the cis isomers the angle  $\theta$  (between C=N and H at carbons 1 and 3) had been chosen as 105° rather than 110° then all of the  $\beta$  angles would be about 10° higher than those specified here.

870

### EXPERIMENTAL

### Melting points have been corrected against known standards.

### trans-2,2,4,4-Tetramethylcyclobutane-1,3-diformamide

To an ice-cooled mixture of *cis*- and *trans*-2,2,4,4-tetramethylcyclobutane-1,3-diamine (13) (44 g, 0.33 mole) was added 60 g (1.3 mole) of 98 + % formic acid. The solid was heated until, after bubbling ceased when the pot temperature reached 260°, all water and formic acid had distilled off. The residue, m.p. 175-222°, weighed 60 g (90%) and was finely ground before it was eluted with 400 ml of boiling 95% ethanol to leave 26 g, m.p. 240-244°. Three crystallizations from dioxane raised the melting point to 257-258°, 22 g. By repetition of this procedure with the evaporated mother liquor from the initial isolation of both geoisomers an additional 6 g, m.p. 257-258°, was isolated. This total yield of the trans isomer was 47% of the 91% yield of both isomers. Calc. for  $C_{10}H_{18}N_2O_2$ : C, 60.5; H, 9.16; N, 14.1. Found: C, 60.3; H, 9.14; N, 14.2.

#### cis-2,2,4,4-Tetramethylcyclobutane-1,3-diformamide

The 400 ml of ethanolic extract mentioned above was concentrated to a volume of 100 ml and 24 g, m.p. 160–185°, crystallized out. These crystals were dissolved in 100 ml of boiling 95% ethanol, and 500 ml of ethyl acetate was added. Upon chilling, 20.5 g crystallized, m.p. 205–212°. This portion was recrystallized four times from ethanol – ethyl acetate (1:3), 15 g, m.p. 216–217°. An additional 12 g of this pure cis isomer was obtained via the repetition step used in the isolation of the additional trans isomer. The total amount of cis isomer (27 g, m.p. 216–217°) amounted to 45% of the combined yield (91%) of formamides. Calc. for  $C_{10}H_{18}N_2O_2$ : C, 60.6; H, 9.16; N, 14.1. Found: C, 60.5; H, 9.17; N, 14.0.

#### cis-2,2,4,4-Tetramethylcyclobutane-1,3-diisocyanide

A suspension of 19.8 g (0.1 mole) of *cis*-tetramethylcyclobutane-1,3-diformamide (m.p. 216-217°) in 100 ml of barium-oxide-dried pyridine and 65 ml of petroleum ether (b.p. 40-60°) was ice-cooled and stirred while 24 g (0.156 mole) of freshly distilled phosphorus oxychloride was added dropwise during 10 minutes. The suspension became cheesy and blue-green. Subsequent reflux for 30 minutes at 55° was followed by the addition of 200 ml of ice water with cooling of the system, which was then thrice extracted with a total of 200 ml of petroleum ether (b.p. 40-60°). The extract was washed with 2% hydrochloric acid, then water, and finally was dried by use of anhydrous magnesium sulphate. Vacuum evaporation left 11 g (67%) of a brown solid, m.p. 46-54°. This was sublimed at 40° (10 mm) to give 9.7 g, m.p. 57.5-58°, colorless. The substance was decomposed (5 days to an oil) by ultraviolet radiation, maximum at 360 m $\mu$ . In a potassium bromide pellet (1/400 by weight) it absorbed at the following cm<sup>-1</sup>: 2970 (s); 2950 (s, shoulder); 286 (w); 2135 (s); 2040 (vw), 1465 (s), 1455 (m); 1400, 1388, 1375 (m); 1362, 1325, 1280 (m), 1215 (w), 1185 (m); 1077, 1065, 1032 (m); 975 (s); 797, 771 (m). Calc. for C<sub>10</sub>H<sub>14</sub>N<sub>2</sub>: C, 74.0; H, 8.69; N, 17.3. Found: C, 73.9; H, 8.65; N, 16.9.

When 0.01 mole of this diisonitrile in 3 ml of acetic acid was heated to 100° for 5 minutes the vacuumevaporated system left 98% of crude cis diformamide, m.p. 195–205°. Crystallization from dioxane yielded 80% of the crude product, m.p. 216–217°, m.m.p. not depressed.

Bromine was added to a solution of 0.162 g (0.001 mole) of the diisonitrile in 25 ml of hexane until a faint yellow color persisted. Although crystals separated, the system was concentrated under vacuum to a volume of 5 ml before 0.29 g (68% as the tetrabromide) was filtered, m.p. 128–129°. A second crop (0.21 g, 44%) was obtained by complete evaporation of solvent, m.p. 110–129°. This tetrabromide was too unstable for routine analysis. It was soluble in water but insoluble in diethyl ether.

# cis-2,2,4,4-Tetramethylcyclobutane-1,3-dicyanide

When 3.42 g (0.02 mole) of the cis diisocyanide was heated in a sealed tube at 320° (electric oven) for 3 minutes and cooled the resulting crystals melted at 89–97°. Crystallization from carbon tetrachloride and from 4:6 aqueous ethanol gave 2.91 g (85%) of rearranged product, m.p. 99.5–100.5°, unreactive toward bromine. In potassium bromide pellets (1/400) it absorbed at cm<sup>-1</sup> as follows: 2970 (s), 2950 (s), 2880 (w), 2240 (s); 1465 (s), 1455 (m, shoulder), 1403 (w), 1395 (w), 1385 (m); 1282 (m), 1200 (m), 1180 (s). Calc. for  $C_{10}H_{14}N_2$ : C, 74.0; H, 8.69; N, 17.3. Found: C, 74.2; H, 8.79; N, 17.4.

# trans-2,2,4,4-Tetramethylcyclobutane-1,3-diisocyanide

### A. From Trans Diformamide

A finely ground suspension of 19.8 g (0.1 mole) of *trans*-2,2,4,4-tetramethylcyclobutane-1,3-diformamide (m.p. 256–257°) in 100 ml of barium-oxide-dried pyridine and 65 ml of petroleum ether (b.p. 40–60°) was ice-cooled and strongly stirred while 24 g (0.156 mole) of freshly distilled phosphorus oxychloride was added dropwise during 10 minutes. The cheese-like green suspension was heated subsequently for 1 hour at 55° and then was chilled while 200 ml of ice water was added. The solid and the non-aqueous phases were separated. The aqueous phase was repeatedly extracted with a total of 150 ml of petroleum ether (b.p. 40–60°). This extract was combined with the solid phase and the non-aqueous phase, and the whole was evaporated. The residue was digested with 1% hydrochloric acid, then with aqueous sodium bicarbonate, and finally with water.

When this crude product was dried it weighed 13 g (80%, m.p. 136–138°) and was almost soluble in 250 ml of hot commercial hexane. This solution yielded 11.2 g (69%) of colorless trans diisocyanide, m.p. 138–139°, in several crops when it was cooled and concentrated. Calc. for  $C_{10}H_{14}N_2$ : C, 74.0; H, 8.69; N, 17.3. Found: C, 74.0; H, 8.92; N, 17.3. The trans diisocyanide absorbed in 2% carbon tetrachloride solution as follows: 2960 (s), 2940 (m), 2880 (w), 2140 (s), 2065 (w), 1470 (s), 1460 (m), 1455 (m), 1329 (m), 1383 (m), 1352 (m), 1240 (w), 1190 (w), 998 (m), 977 (w), 954 (w).

B. By Chromatography of a Cis-Trans Mixture

A mixture of 50 mg each of the cis and trans diisocyanides was dissolved in 5 ml of benzene plus 5 ml of commercial hexane and was washed by the same solution onto 22 cm of alumina on a column 1 cm in diameter and 20 cm long (150–170 mesh activated 10 hours at 200° C). The column was washed with 150 ml of the same solution and then was developed with a solution of commercial hexane – ethyl acetate (50:1), which gave a first fraction, m.p. 57.5–58.5° C. A second fraction, m.p. 138–139°, was developed with pure ethyl acetate.

The trans diisocyanide, m.p. 138–139°, could be reconverted to the trans diformamide if it were heated (0.005 mole) in 8 ml of acetic acid for 5 minutes at 100°. A quantitive yield was obtained by vacuum evaporation of the solvent and crystallization of the residue from boiling water. A mixture melting point with original trans diformamide was not depressed.

Like the corresponding derivative of the cis diisocyanide, the tetrabromide of the trans diisocyanide was unstable, although the two were not identical (m.m.p. depressed). An 88% yield was obtained, m.p. 129–130°, when all but 5 ml of solvent was evaporated from the system comprised of 0.198 g diisocyanide, 40 ml of petroleum ether (b.p. 40–60°), and bromine in slight excess.

By contrast to the cis diisocyanide, exposure to ultraviolet light (max. 360 m $\mu$ ) during a month did not depress the melting point of the trans diisocyanide.

#### trans-2,2,4,4-Tetramethylcyclobutane-1,3-dicyanide

When 1.62 g (0.01 mole) of trans diisocyanide (m.p. 138–139°) was heated in a sealed tube for 4 minutes at 310° (electric oven) it was converted to the dinitrile, m.p. 153–154° after crystallization from carbon tetrachloride and 4:6 water–ethanol. The product (yield 1.34 g, 83%) did not react with bromine in carbon tetrachloride. In potassium bromide pellets (1/400) it absorbed at the following cm<sup>-1</sup>: 2970 (s), 2950 (m), 2880 (w), 2250 (m), 1470 (s), 1460 (m), 1395 (s), 1385 (s); 1205, 1188, 1177 (m) with no further absorption down to 650 cm<sup>-1</sup>. Calc. for C<sub>10</sub>H<sub>14</sub>N<sub>2</sub>: C, 74.0; H, 8.69; N, 17.3. Found: C, 73.8; H, 8.62; N, 17.2.

#### trans-2,2,4,4-Tetramethylcyclobutane-1,3-dicarboxylic Acid

A solution either of 3 g of *cis*- or *trans*-tetramethylcyclobutanedicyanide (0.018 mole) in 15 ml of 70% (w/w) sulphuric acid was boiled for 7 minutes. The cooled system was diluted with 20 ml of water, then was continuously extracted with diethyl ether. The ether solution, water washed to remove sulphuric acid and dried by use of magnesium sulphate, was evaporated to a volume of 25 ml, whereupon 2.2 g (59%) of crude trans acid, m.p. 264-266°, separated and was filtered off. Crystallization from water raised this melting point to 270-271.5° (sample introduced at 268°). Calc. for C<sub>10</sub>H<sub>16</sub>O<sub>4</sub>: C, 60.0; H, 8.06. Found: C, 60.0; H, 8.19. The dimethyl ester, prepared by use of diazomethane, melts at 8-10° after crystallization from petroleum ether (b.p. 40-60°). Titration of an aqueous acetone solution gave a  $pK_A^1$  of 6.60; the  $pK_A^2$  value could not be observed.

### cis-2,2,4,4-Tetramethylcyclobutane-1,3-dicarboxylic Acid

The ether filtrate from which the trans acid was isolated according to the procedure described above was evaporated to leave 1.2 g, m.p. 233–236°. Crystallization from water raised this m.p. to 235–236°. Calc. for  $C_{10}H_{16}O_4$ : C, 60.0; H, 8.06. Found: C, 59.8; H, 8.12. The dimethyl ester (from diazomethane) melted at 3–6° after crystallization from petroleum ether (b.p. 40–60°). The p $K_A$ <sup>1</sup> found for an aqueous acetone solution was 6.78.

### 2,2,4,4-Tetramethylcyclobutane

The disemicarbazone of 2,2,4,4-tetramethylcyclobutanedione was prepared in 98% yield, m.p. 213 (decomp.) (23).

Into a solution prepared from 229 g (10 atom weight) of sodium and 2800 ml of diethylene glycol at 110° was added (at 130°) 305 g (1.2 mole) of the disemicarbazone, and the temperature was raised. At 155° nitrogen evolution commenced and continued during 45 minutes after the temperature had been raised to 210° during 30 minutes. The vapors were caught in a dry ice trap. Then 2 liters of water were added to the residue and it was steam-distilled.

The non-aqueous phase of steam distillations, the ether extract of the aqueous phases, and the trap condensates from five such experiments were combined, washed with 1% hydrochloric acid, dried by use of magnesium sulphate, and distilled (760 mm) to give 8 g b.p.  $75-84^{\circ}$ , 20 g b.p.  $84-85^{\circ}$ , and 50 g b.p.  $85^{\circ}$ . After this tetramethylcyclobutane had been separated (b.p. according to Herzog 86-87° at 745 mm) subsequent fractions were distilled off: 52 g b.p.  $62-87^{\circ}$  (42-38 mm), 176 g b.p.  $96^{\circ}$  (52 mm), 40 g b.p.  $96-124^{\circ}$  (52 mm), leaving a pot residue which crystallized but was discarded.

872

873

#### 2,2,4,4-Tetramethylcyclobutanone

The 176 portion (conforming approximately with the b.p.  $90-93^{\circ}$  at 45 mm reported by Herzog from tetramethylcyclobutane hydrazone) represents a 23% yield of this substance. A solution of 155 g (1.1 mole) in 350 ml of conc. hydrochloric acid was shaken until a sample of the non-aqueous top phase did not diminish in volume when treated with fresh conc. hydrochloric acid nor did it produce cloudiness in the test-acid phase during 5 minutes. The top layer was then separated and was augmented by ether extractions of the aqueous phase. The combination (ether solution of the non-aqueous phase) was washed acid free by means of water, then dried by use of magnesium sulphate, and was distilled at 760 mm to yield 13 g b.p. 124–130.5° and 108 g b.p. 130.5–131°. This latter fraction (77% on the basis of hydrazone used) was redistilled and the distillate was allowed to crystallize (slowly) at about 19° C. The crystalline portion (100 g) with camphor-like odor melted at 19–21°,  $n_D^{20}$  1.41425. This ketone, which boiled like that of Herzog (128.5–129° at 745 mm), absorbed in 1.4% carbon tetrachloride at  $cm^{-1}$  as follows: 2970 (s), 2900 (m), 1770 (s), 1470 (m), 1460 (m), 1390 (m), 1370 (m), 1240 (w), 1200 (w), 1160 (w), 1028 (s), 910 (m). The 2,4-dinitrop phenylhydrazone of this ketone melted at 114–115°. The ketone was recovered (80%) unchanged upon attempted conversion to the amine by means of the Leuckart reaction using a nickel catalyst (29).

## 2,2,4,4-Tetramethylcyclobutanone Oxime

A solution of 6.3 g (0.05 mole) of ketone in 50 ml of ethanol was treated with 3.8 g (0.055 mole) of hydroxylamine hydrochloride in 4.5 ml of water and 5 ml of pyridine. After 2 hours at 60° dilution with 200 ml of water gave 6.9 g (98%) of oxime, m.p. 88.5–89.7°. Crystallization by solution of 1 g in 10 ml of water plus 8.5 ml of methanol at 70° raised the melting point to 89–90°. The oxime was quite soluble in petroleum ether (b.p. 40–60°) and in diethyl ether. Calc. for C<sub>8</sub>H<sub>15</sub>NO: C, 68.0; H, 10.8; N, 9.92. Found: C, 68.2; H, 10.4; N, 9.65. A 2% solution in carbon tetrachloride showed the following absorption at cm<sup>-1</sup>: 3620 (m); 3240, 3140 (s); 2980, 2950, 2860 (s); 1705 (m); 1465, 1455, 1440 (s); 1380, 1370, 1345 (m); 1230, 1197, 1162 (w); 1070 (m); 980 (w); 950, 930, 920, 893 (s).

## 2,2,4,4-Tetramethylpyrrolidine

A solution in 800 ml of absolute diethyl ether of 63.5 g (0.45 mole) of the oxime described above was added during 30 minutes to a stirred suspension of 29.2 g (0.77 mole) of lithium aluminum hydride. The suspension was refluxed for 8 hours. The now-light-grey and thickened suspension was stirred with 12 g (0.2 mole) of acetone and, after 1 hour, with 100 ml of water. The non-aqueous layer was separated and the aqueous layer was extracted by use of 50 ml of diethyl ether. The combination of non-aqueous phases was washed with a little water, and then with 5% hydrochloric acid. The aqueous acid layer was washed with a little ether, then was basified, and continuously extracted during 1 day by use of diethyl ether. The extract, dried by use of potassium carbonate, was fractionally distilled. The main fraction, b.p. 128–132°, weighed 30 g (53%). Calc. for C<sub>8</sub>H<sub>17</sub>N: C, 75.6; H, 13.47; N, 11.0. Found: C, 75.3; H, 13.5; N, 11.2.

This 2,2,4,4-tetramethylpyrrolidine is strongly basic and slightly soluble in water. Reactions with nitrous acid and with benzene sulphonyl chloride show that it is a secondary amine. In carbon tetrachloride solution it shows medium absorption at 3250, 3150, and 2680 cm<sup>-1</sup>. It reacts with phenylisocyanate to give N-phenyl-carbamyl-2,2,4,4-tetramethylpyrrolidine, m.p. 157–157.5°, after crystallization from petroleum ether (b.p. 90–100°, 0.45 g from 10 ml); from petroleum ether (b.p. 60–70) – chloroform, 1:1; from carbon tetrachloride; and from chloroform – petroleum ether (b.p. 90–100), 1:1. Calc. for  $C_{15}H_{22}N_2O$ : C, 73.1; H, 9.00; N, 11.4. Found: C, 73.0; H, 8.93; N, 12.0. The amine forms a picrate, m.p. 132–133.5°, and a *p*-nitrobenzoyl derivative, m.p. 184.5–186.5°.

#### 2.2.4.4-Tetramethylcyclobutylamine

A solution of 11.3 g of the oxime (m.p. 88-89°) in 120 ml of absolute ethanol was saturated with ammonia at  $+5^{\circ}$  and reduced by hydrogen using pelleted Raney nickel (British Drug House) from which the paraffin was removed by use of petroleum ether. The reduction was first carried out at 500 p.s.i. (90°) for 45 minutes and then at 14,000 p.s.i. (90°) for 3 hours. Stirring in the stainless steel container was effected magnetically with a bar constructed by vacuum shrinkage of Corning 7052 glass onto Kovar alloy which had previously been treated with hydrogen at 1100° C. The filtered system was then distilled through a 10-in. Vigreux column at atmospheric pressure, to obtain finally 1.2 g b.p. 80-134°, 0.4 g b.p. 134-136°, and 4 g b.p. 136°. The 0.2-g and 0.4-g portions were combined with the distilled ethanol from the original hydrogenation product, acidified with formic acid, and distilled, to give finally 2.8 g of the formamide described below, b.p.  $246^{\circ}$ . The total yield may thus be calculated as 63%, of which 4 g is free amine. The absorption spectrum of the amine in 7% solution in carbon tetrachloride was found in  $cm^{-1}$  to be: 3480 (w); 3200 (w); 2970, 2870 (s); 2750 (w); 1620 (m); 1470, 1455 (m), 1450 (m, shoulder); 1390 (w, shoulder); 1380 (w, shoulder); 1360 (m); 1290 (w), 1140 (m); 1110 (m); 1010 (w); 980 (w); 965 (m); 880 (m, broad). The amine evolved nitrogen on treatment with nitrous acid, formed the carbonate salt readily in air, and was insoluble in water or 5% aqueous sodium hydroxide but was readily soluble in 5% hydrochloric acid. Calc. for C<sub>8</sub>H<sub>17</sub>N: C, 75.3; H, 13.6; N, 11.0. Found: C, 74.9; H, 13.1; N, 10.4. The amine formed a picrate, m.p. 207°. It was converted into the phenylthiourea derivative in 97% yield, m.p. 151-154°. After two crystallizations from petroleum ether (b.p. 90-100°) and 1:1 ethanol-water this derivative melted at 153-154°. Calc. for C15H22N2S: C, 68.6; H, 8.45; N, 10.7. Found: C, 68.5; H, 8.33; N, 10.8.

Can. J. Chem. Downloaded from www.nrcresearchpress.com by UNIVERSITY OF MICHIGAN on 11/17/14 For personal use only.

#### CANADIAN JOURNAL OF CHEMISTRY. VOL. 41, 1963

#### 2,2,4,4-Tetramethylcyclobutylformamide

A solution of 3.8 g (0.03 mole) of tetramethylcyclobutylamine in 1.8 g (0.04 mole) was prepared with cooling and then was heated gradually to 205° to distill off formic acid and water. The residue was distilled at 242–245°. This distillate (4.1 g, 87%), m.p. 65–67°, was crystallized from petroleum ether, first of b.p. 40–60° and then of b.p. 90–100°, by chilling to -50°. Finally the formamide was sublimed, m.p. 68–68.8°. Calc. for C<sub>9</sub>H<sub>17</sub>NO: C, 69.6; H, 11.0; N, 9.02. Found: C, 69.4; H, 11.2; N, 8.77. The formamide, soluble in organic solvents but insoluble in water, showed the following absorptions in 1.5% carbon tetrachloride in cm<sup>-1</sup>: 3460 (m), 3920 (m), 3210 (m), 3100 (m), 2960 (s), 2870 (s), 1690 (s), 1480 (s), 1460 (s), 1380 (s), 1370 (s), 1325 (m), 1300 (m), 1250 (m), 1235 (m), 1220 (m), 1190 (m), 1135 (m), 1070, 1028, 1015, 965, 878, 555 (w).

### 2,2,4,4-Tetramethylcyclobutylisocyanide

A procedure identical with those described above was effected using 6 g (0.04 mole) of the formamide, from which 2.9 g (60%) of isocyanide, b.p. 160° (m.p. -25.5 to  $-24.5^{\circ}$ ), was obtained,  $n_D^{20}$  1.4506. It reacted with bromine in carbon tetrachloride. In 2% solution in carbon tetrachloride it showed the following absorptions at cm<sup>-1</sup>: 2960, 2860 (s, with shoulder at 2850); 2140 (s); 1460, 1450, 1445 (m); 1380, 1370 (m); 1330, 1280, 1250, 1230, 1190, 1130, 1100, 1035, 1005, 970 (w). Calc. for C<sub>9</sub>H<sub>15</sub>N: C, 78.8; H, 11.0; N, 10.2. Found: C, 78.9; H, 10.9; N, 10.0. When 0.2 g of the isocyanide was boiled for 10 minutes in 2 ml of acetic acid it was recovered in 91% yield as the formamide, m.p. 65-67°, m.m.p. not depressed.

#### Electrical Measurements

The dielectric constants of solutions were determined in the customary manner (30). The apparatus described recently (31) was used for measurement of the dielectric constants of the nitriles and isonitriles in the solid state. Because of the unexpected lack of correlation among the measured distortion polarizations of the geoisomeric nitriles and isonitriles a large number of experiments were made. These data made it possible to examine the unexplained phenomenon that the slope of the linear plot of apparent dielectric constant with respect to pellet thickness for any substance is variable from run to run. When the extrapolated dielectric constants of a series of six separate determinations of terephthalonitrile were plotted against the slopes,  $\epsilon$ /thickness, a reasonably linear relationship was found which showed that change in slope from 0.5 to 2.0 would cause a change in dielectric constant from 2.945 to 2.940. Therefore it appears that an uncontrolled error is present in the determination. However, the variation in dielectric constant shows that this error is less than that inherent in the overall determination of solid dielectric constant.

# ACKNOWLEDGMENTS

The authors wish to thank the National Research Council and the Defence Research Board of Canada for financial aid. They are grateful to the Tennessee Eastman Company for aid with materials and n.m.r. analyses. They acknowledge valuable technical aid from Mr. Helmut Huber.

# REFERENCES

- T. P. WILSON. J. Chem. Phys. 11, 369 (1943). S. H. BAUER and J. Y. BEACH. J. Am. Chem. Soc. 64, 1142 (1942). I. E. COOP and L. E. SUTTON. J. Chem. Soc. 1269 (1938). W. N. LIPSCOMBE and V. SCHOMAKER. J. Chem. Phys. 14, 475 (1946).
- J. D. DUNITZ. Acta Cryst. 2, 1 (1949) 5.
- 6.
- H. H. CLAASSEN. J. Chem. Phys. 18, 543 (1950).
  H. P. LEMAIRE and R. L. LIVINGSTON. J. Chem. Phys. 18, 569 (1950).
  W. W. EDYELL and D. C. WEIBLEIN. J. Chem. Phys. 18, 571 (1950).
- H. P. LEMAIRE and R. L. LIVINGSTON. J. Am. Chem. Soc. 74, 5732 (1952). J. D. DUNITZ and V. SCHOMAKER. J. Chem. Phys. 20, 1703 (1952). 10.
- J. P. MCHUGH. Doctoral Dissertation, California Institute of Technology, Pasadena, Calif. 1957. P. PODLESCHKA, L. WESTLAND, and G. F WRIGHT. Can. J. Chem. 36, 574 (1958). 11.
- 12.
- 13. Tennessee Eastman Company, Kingsport, Tennessee, U.S.A. 14. A. W. HOFMANN. Ann. 144, 114 (1867).

- A. W. HOFMANN. Ann. 146, 107 (1888).
   I. Ugi and R. Meyr. Ber. 93, 239 (1961).
- 17. A. GAUTIER. Ann. Chim. (Paris), Ser. 4, 17, 233 (1869). 18. J. U. NEF. Ann. 280, 291 (1894).
- F. KAUFLER. Ber. 34, 1578 (1901) 19.

- F. KAUFLER. Ber. **34**, 1578 (1991).
   J. WADE. J. Chem. Soc. **81**, 1596 (1902).
   W. H. PERKIN, JR. and J. L. SIMONSEN. J. Chem. Soc. **95**, 1176 (1909).
   C. P. SMYTH. Dielectric behavior and structure. McGraw-Hill, New York. 1955.
   H. L. HERZOG and E. R. BUCHMAN. J. Org. Chem. **16**, 99 (1951).
   C. C. MEREDITH, L. WESTLAND, and G. F WRIGHT. J. Am. Chem. Soc. **79**, 2385 (1957).

- H. SAWATZKY and G. F WRIGHT. Can. J. Chem. 36, 1555 (1958).
   P. FRIEDLANDER and F. M. ROBERTSON. J. Chem. Soc. 3083 (1956).
   R. H. HASEK, E. U. ELAM, J. C. MARTIN, and R. G. NATIONS. J. Org. Chem. 26, 700 (1961).
   D. H. WHIFFEN and H. W. THOMPSON. J. Chem. Soc. 1005 (1946).
   A. N. KOST and J. J. GRANDBERG. J. Gen. Chem. USSR, 25, 1377 (1955).
   C. C. MEREDITH and G. F WRIGHT. Can. J. Chem. 38, 1177 (1960).
   M. BEDARD, H. HUBER, J. L. MYERS, and G. F WRIGHT. Can. J. Chem. 40, 2278 (1962).

esearcnpress.com by UNIVERSITY OF MICHIGAN on 11/17/14 For personal use only.