Hetera-*p*-carbophanes. I. Hetera-*p*-carbophanes Containing Two Amide Groups

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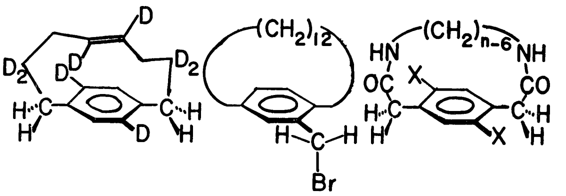
Several hetera-*p*-carbophanes containing two amide groups in the ansa chain were synthesized by the high-dilution method. Those which have shorter ansa chains than 15 atoms show no sign of the internal rotation of the benzene ring, even at higher temperatures, whereas that which has the ansa chain of 16 atoms shows no sign of the freezing of the motion, even at lower temperatures. The infrared spectra of these compounds suggest that the amide groups in these compounds exist as the *s-cis* conformation.

The restricted rotation of an aromatic ring in paracyclophanes was first demonstrated by the optical resolution of oxygen-containing hetera-*p*-carbophanes[2] by Lüttringhaus.[3] Later, Cram and his co-worker succeeded in resolving a [2.2]paracyclophane derivative,[4] and Blomquist *et al.* reported the first resolution of carbo-*p*-carbophanes in 1961.[5] A faster but still hindered rotation can, of course, be observed by the dynamic nuclear magnetic resonance technique. Thus, Cope *et al.* published a paper on the hindered rotation of an olefinic cyclophane (I) using the nonequivalence-collapse of the aromatic and aliphatic protons.[6] On the other hand, Nakazaki *et al.* studied the nonequivalence of protons of an XCH_2 group which is attached to the benzene ring of a paracyclophane (II).[7]

In general, paracyclophanes should have nonequivalent benzylic methylene protons, provided that the aromatic ring is unsymmetrically substituted and the rotation of the ring is slow enough on the NMR time scale. Actually, Cope *et al.* pointed out that the benzylic protons of I were nonequivalent.[6] In the compounds of the type of II, the conformational distribution will, in principle, vary with the temperature because the stabilities of three rotamers concerned with the internal rotation about the C_{arom}–C_{CH_2X} bond are different. Thus, it is the authors' opinion that much more study is needed to clarify the various effects on the rate of the rotation of the aromatic ring in paracyclophanes and in order to discuss the effect of the variation in the population of the rotamers on the apparent barriers to the internal rotation.

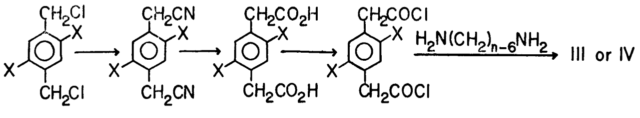
This paper will deal with the syntheses and some spectroscopic properties of 10 hetera-*p*-carbophanes (III and IV) as the first probe of a series. The reason for the selection of these compounds is the simplicity of the analysis of the line shape. The rigidity and the mobility of these compounds as revealed by NMR spectroscopy will be reported.



I II III$_n$ X=H (n=12—16)
IV$_n$ X=Me (n=12—16)

Experimental

Syntheses. The hetera-*p*-carbophanes, III$_n$ and IV$_n$,[8] were synthesized by the high-dilution method from the corresponding 1,4-phenylenediacetyl dichloride and α,ω-diamines. The routes of the syntheses of the former are depicted in Scheme 1, while the latter compounds were of commercial origin.



(V) (VI) (VII) (VIII)

Scheme 1.

All the melting points are uncorrected.

α^1,α^4-Dichlorodurene (V, X=Me). A mixture of 53 g (0.5 mol) of *p*-xylene, 106 g (1.3 mol) of 37% formaline, and 530 g of concentrated hydrochloric acid was heated at 60—70°C for 7—15 hr with stirring and while introducing dry hydrogen chloride. The resulting crystals were filtered, and the filtrate was extracted with ether. The crystals and the ether extract were combined and were thoroughly washed with a saturated aqueous solution of sodium bicarbonate and then with a sodium chloride solution. After drying over magnesium sulfate, the solvent and some α^2-chloro-1,2,4-trimethylbenzene were evaporated to yield the crude α^1,α^4-dichlorodurene. Recrystallization from ether gave 65 g of the pure compound; mp 128—129°C (lit, mp 133°C).[9]

α^1,α^4-Dicyanodurene (VI, X=Me). A mixture of 50 g (0.25 mol) of the dichloride (V, X=Me), 37 g (0.75 mol) of powdered sodium cyanide, 800 ml of ethanol, and 150 ml of water was refluxed for 30 hr. The subsequent working-up of the reaction mixture in the usual manner gave 37 g (80%) of the crude dicyanide (mp 136—138°C), which was directly

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[1] To whom the correspondence should be addressed.

[2] F. Vögtle and P. Neumann, *Tetrahedron*, **26**, 5847 (1970).

[3] A. Lüttringhaus and H. Graler, *Ann. Chem.*, **550**, 67 (1940); **557**, 108, 112 (1945); A. Lüttringhaus and G. Eyring, *ibid.*, **604**, 111(1957).

[4] D. J. Cram and N. L. Allinger, *J. Amer. Chem. Soc.*, **77**, 6289 (1955).

[5] A. T. Blomquist, R. E. Stahl, Y. C. Meinwald, and B. H. Smith, *J. Org. Chem.*, **26**, 1687 (1961).

[6] G. M. Whitesides, B. A. Pawson, and A. C. Cope, *J. Amer. Chem. Soc.*, **90**, 639 (1968).

[7] M. Nakazaki, K. Yamamoto, and S. Okamoto, *Tetrahedron Lett.*, **1969**, 4597; This Bulletin, **45**, 1562 (1972).

[8] The suffix denotes the number of atoms which constitute the ansa chain.

[9] J. V. Braun and J. Nelles, *Ber.*, **67**, 1094 (1934).

Table 1. Hetera-*p*-carbophanes

Compound	Molecular formula	Mp (°C)	Analytical data C	H	N(%)	Mol wt (M⁺)	Recrystallization solvent	Synthetic method (%)	IR (KBr) (cm⁻¹) ν_{NH}	Amide I	Amide II
III_{12}	$C_{16}H_{22}N_2O_2$	220.0—221.0	70.23	7.89	9.91[a]	274[a]	MeOH	A (<5)	3270	1640	1540
			70.04	8.08	10.21[a]	274[a]					
III_{13}	$C_{17}H_{24}N_2O_2$	290.5—291.5	70.22	8.71	9.42	288	MeOH	B (<5)	3300	1640	1560
			70.80	8.39	9.71	288					
III_{14}	$C_{18}H_{26}N_2O_2$	269.5—270.5	71.22	8.54	8.97	302	MeOH	B (<5)	3260	1640	1570
			71.49	8.67	9.26	302					
III_{15}	$C_{19}H_{28}N_2O_2$	269.0—270.0	72.08	9.07	8.71	316	MeOH	B (18)	3260	1635	1550
			72.12	8.92	8.85	316					
III_{16}	$C_{20}H_{30}N_2O_2$	289.0—290.0	72.60	9.00	8.23	330	MeOH	B (22)	3290	1640	1570
			72.69	9.15	8.48	330					
IV_{12}	$C_{18}H_{26}N_2O_2$	237.5—238.5	71.66	8.82	9.10	302	MeOH	A (13)	3320	1645	1545
			71.49	8.67	9.26	302					
IV_{13}	$C_{19}H_{28}N_2O_2$	226.0—227.5	71.98	8.65	8.63	316	MeOH	B (4.5)	3320	1645	1545
			72.12	8.92	8.85	316					
IV_{14}	$C_{20}H_{30}N_2O_2$	192.5—194.0	72.77	9.18	8.25	330	CH_2Cl_2–ether	B (5.7)	3320	1650	1555
			72.69	9.15	8.48	330					
IV_{15}	$C_{21}H_{32}N_2O_2$	200.0—201.0	73.00	9.51	7.84	344	CH_2Cl_2	B[b] (7.1)	3300	1640	1545
			73.22	9.36	8.13	344					
IV_{16}	$C_{22}H_{34}N_2O_2$	236.5—237.0	73.83	9.27	7.59	358	MeOH	B[b] (2.8)	3300	1640	1545
			73.70	9.56	7.81	358					

a) The numerical data in the upper column are those found and those in lower column are the calculated values.

b) The reaction was carried out at the boiling point of tetrahydrofuran without adding triethylamine.

used for the preparation of 2,5-dimethyl-1,4-phenylenediacetic acid. IR(KBr): 2240 cm⁻¹ (ν_{CN}). NMR ($CDCl_3$, δ from internal TMS): 2.31 (6H, s); 3.62 (4H, s); 7.20 (2H, s).

*α^1,α^4-Dicyano-*p*-xylene (VI, X=H)* was obtained similarly in an 89% yield; mp 95.5—96.5°C (lit, mp 96°C).[10] IR (KBr); 2250 cm⁻¹ (ν_{CN}). NMR ($CDCl_3$, δ from internal TMS): 3.76 (4H, s); 7.36 (4H, s).

2,5-Dimethyl-1,4-phenylenediacetic Acid (VII, X=Me). A mixture of 37 g (0.2 mol) of the dicyanide (VI, X=Me), 60 ml of concentrated sulfuric acid, and 80 ml of water was refluxed for 3 hr. The reaction mixture was then poured into ice–water after cooling to yield 20 g (39%) of the crude product. The sample, after purification, melted at 257—261°C with decomposition. IR(KBr); 1700 cm⁻¹ (ν_{CO}).

1,4-Phenylenediacetic acid (VII, X=H) was prepared similarly in a 49% yield. Mp 227—230°C (decomposition) (lit, mp 240—241°C).[11] IR(KBr): 1710 cm⁻¹ (ν_{CO}).

2,5-Dimethyl-1,4-phenylenediacetyl Dichloride (VIII, X=Me). A mixture of 10 g (38 mmol) of the dicarboxylic acid (VII, X=Me), 20 g (180 mmol) of thionyl chloride, and 120 ml of absolute ether was refluxed for 5 hr. The unreacted dicarboxylic acid was removed by filtration, and the exess thionyl chloride and the solvent were evaporated under reduced pressure to give 8 g (68%) of yellow crystals. The crude dichloride was used for the next reaction without further purification.

1,4-Phenylenediacetyl dichloride was obtained similarly in a 69% yield.

*Syntheses of Hetera-*p*-carbophanes (III and IV).* These compounds were prepared by two general methods. Method A was used for the compounds which were soluble in a benzene–toluene mixture. For the compounds which were sparingly soluble in a benzene–toluene mixture, the use of method B was preferable. The method of preparation, the melting points, the analytical data, and the solvents of recrystallization for each compound are summarizd in Table 1.

Method A. This method will be described by taking the case of 14,17-dimethyl-3,10-diaza-2,11-dioxo[12]paracyclophane (IV_{12}) as an example.

A solution of 3.4 g (13 mmol) of 2,5-dimethyl-1,4-phenylenediacetyl dichloride in 350 ml of a 1 : 1 (v/v) benzene–toluene mixture was slowly added to a vigorously-stirred mixture of 4.0 g (40 mmol) of triethylamine, 2.3 g (20 mmol) of hexamethylenediamine, and 500 ml of 1 : 1 (v/v) benzene–toluene over a period of 40 hr. The mixture was freed from any solid material by filtration and then evaporated *in vacuo* to give 0.5 g (13%) of pale yellow crystals. The recrystallization of the product from methanol afforded colorless, granular crystals; mp 237.5—238.5°C.

Method B. This method will be exemplified by the preparation of 3,13-diaza-2,14-dioxo[15]paracyclophane (III_{15}).

A solution of 1.65 g (7 mmol) of 1,4-phenylenediacetyl dichloride in 100—150 ml of tetrahydrofuran was slowly added to a vigorously-stirred and refluxing mixture of 1.5 g (15 mmol) of triethylamine and 1.1 g of nonamethylenediamine in 600—800 ml of tetrahydrofuran over a period of 25 hr, employing a high-dilution apparatus. After the solvent has then been removed, the residue was extracted with 100 —200 ml of dichloromethane. The extract was washed with dilute hydrochloric acid and then with saturated aqueous sodium chloride, and dried over magnesium sulfate. The evaporation of the solvent, after filtration, gave 0.5 g (18%) of pale yellow crystals which were recrystallized several times from methanol or dichloromethane. The pure compound consisted of colorless crystals; mp 269.0—270.0°C.

N,N′-Dipropyl-2,5-dimethyl-1,4-phenylenediacetamide (XV). To a solution of 3 g (31 mmol) of propylamine and 3 g of (30 mmol) of triethylamine in 50 ml of tetrahydrofuran, was added a solution of 2.6 g (10 mmol) of 2,5-dimethyl-1,4-phenylenediacetyl dichloride in 50 ml of tetrahydrofuran,

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[10] A. F. Titly, *J. Chem. Soc.*, **1926**, 515.

[11] F. S. Kipping, *ibid.*, **56**, 21 (1888).

while the temperature was maintained below 5°C. The resulting solid was collected by filtration, washed with water, and recrystallized from methanol. The compound (mp 230.0—231.0°C), was thus obtained in a 1.5 g (50%) yield. IR (KBr): 3300 (ν_{NH}); 1640 (amide I); 1545 (amide II). Found: C, 71.23; H, 9.44; N, 8.96%; mol wt, 304 (M^+). Calcd for $C_{18}H_{28}N_2O_2$: C, 71.02; H, 9.27; N, 9.20%; mol wt, 304.

N,N′-*Dipropyl-1,4-phenylenediacetamide (XIV)* (mp 225.0—226.0°C) was similarly obtained in a 64% yield. IR(KBr): 3260 (ν_{NH}); 1635 (amide I); 1555 cm^{-1} (amide II). Found: C, 69.56; H, 8.86; N, 9.90%; mol wt, 276 (M^+). Calcd for $C_{16}H_{24}N_2O_2$: C, 69.53; H, 8.75; N, 10.14%; mol wt, 276.

1,8-Diaza-9,18-dioxocyclooctadecane (XVI). This compound was prepared in a manner similar to that described for the preparation of hetera-*p*-carbophanes (Method A) from decanedioyl dichloride and hexamethylenediamine. The compound melted at 216.0—218.0°C after recrystallization from dimethylformamide. IR (Nujol mull): 3300 (ν_{NH}); 1640 (amide I); 1545 (amide II). Found: C, 67.53; H, 10.59; N, 9.53%; mol wt, 282 (M^+). Calcd for $C_{16}H_{30}N_2O_2$: C, 68.04; H, 10.71; N, 9.92%; mol wt, 282.

Measurement of the Spectra. The infrared spectra were recorded on either a Hitachi EPI-G2 grating infrared spectrophotometer or a Perkin-Elmer 112G grating spectrophotometer. The NMR spectra were measured on a Hitachi R-20B spectrometer, and the mass spectra, on a Hitachi RMU-6L spectrometer.

Results and Discussion

Internal Rotation of the Aromatic Ring. The observed NMR spectra of III_{12} and IV_{12}—IV_{16} in a deuteriochloroform solution at 34°C are illustrated in Fig. 1. The high-resolution spectra of III_{13}—III_{16} could not be obtained because of their poor solubilities in the appropriate solvents.

It can be pointed out generally that the shapes of the signals of the bridge methylene protons in IV_n reflect the rigidity of the molecule: the compounds with the smaller ring give the complex spectra, while those of the larger ring, give the rather smooth spectra. The chemical shifts of the methylenes of the smaller ring are located in the high magnetic field, suggesting the anisotropy effect of the benzene ring.

The benzylic protons of III_{12} and IV_{16} gave signals of the A_2 type at 3.58 and 3.51 ppm respectively from the internal TMS, whereas those of IV_{12}, IV_{13}, IV_{14}, and IV_{15} gave signals of the AB type at *ca.* 3.54 ppm.

Considerations of the conformations of III_n and IV_n reveal that there are three conformations possible, the isomerism of which is caused by the rotation about the C_{CO}–C_{benzyl} bond: *syn*, *anti*, and *syn′* in Fig. 2.[12]

The Newman projections of these conformations, as separated forms for the two benzylic parts, are given in Fig. 3.

Since these molecules are rather rigid, the exchange among these conformations might be slow on the NMR time scale. However, looking at the data of III_{12}, the possibility that the slow exchange is the cause of the appearance of the AB signals can be rejected: if such were the case, III_{12} should also have

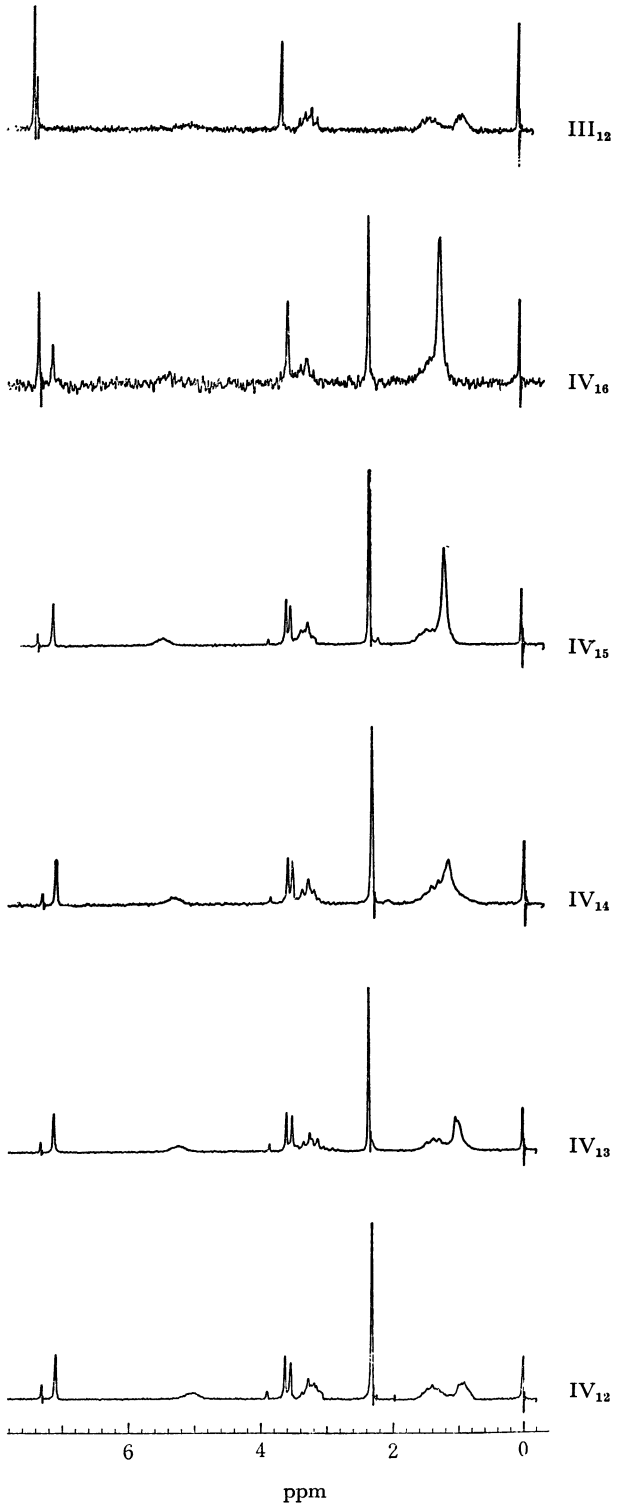

Fig. 1. NMR spectra III_{12} and IV_{12}—IV_{16} in $CDCl_3$ (δ from internal TMS).

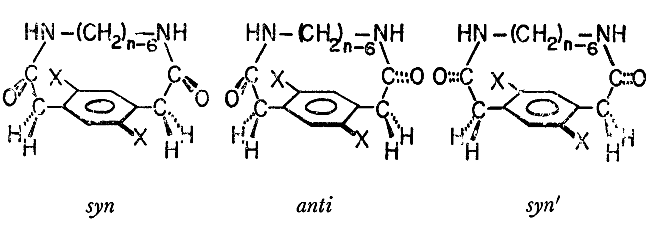

Fig. 2. Rotational isomerism about the C_{CO}–C_{benzyl} bond.

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[12] We are assuming that no isomerization is possible about the amide moiety. See the discussions below.

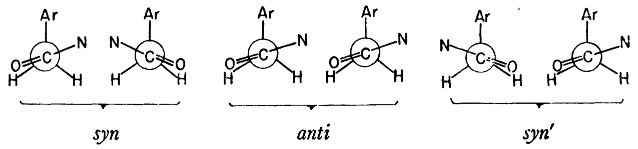


Fig. 3. Newman projections of rotational isomers about the C_{CO}–C_{benzyl} bond.

shown the AB signal for the benzylic protons. Thus, the slow internal rotation of the unsymmetrically-substituted benzene ring is the sole possible cause of the AB-type signals.

At least, at room temperature, the signals suggest that the internal rotation of the dimethylbenzene ring in IV$_{15}$ is slow while that in IV$_{16}$ is fast, on the NMR time scale. The temperature dependence of these spectra was thus studied in an attempt to obtain the kinetic data of the internal rotation: IV$_{15}$ in 1,1,2,2-tetrachloroethane at higher temperatures (34—170°C) and IV$_{16}$ in deuteriochloroform at lower temperatures (34—−50°C). To our suprise, however, the changes in signal shape according to the temperature change are so small that it is impossible to obtain the expected data.

The minimum and maximum free energies of activation may be obtained by applying this equation:[13]

$$\Delta G_c^{\neq} = 4.57 T_c\{9.97+\log_{10}(T_c/\sqrt{\delta\nu^2+6J^2})\}$$

provided that the chemical shifts and the coupling constants are the same for both compounds when the internal rotation is slow enough and that the coalescence temperature (T_C) in the above equation is transferable to any temperature desired. Thus, since the AB quartet of the benzyl methylenes in IV$_{15}$ did not colapse at 443°K, the minimum free energy of activation is obtained as 22.3 kcal/mol. Similarly, since the benzyl methylene signals of IV$_{16}$ did not change in shape even at 223°K,[14] the free energy of activation for the internal rotation must be less than 10.8 kcal/mol. Therefore, the difference in barriers to the internal rotation of the benzene ring is at least 11.5 kcal/mol for these compounds. This large difference in the barriers by changing the number of bridge methylenes by only one is not without precedent. *trans*-Cyclodecene is known to have the barrier of 10.7 kcal/mol[15] by the dynamic NMR, and *trans*-cyclononene, one of 20 kcal/mol by the conventional kinetic technique.[16]

It is noteworthy that, although the coupling constants did not change, even the benzylic methylene protons change their chemical shifts due to the temperature variation. This is a rather unexpected phenomenon, because no reason for the change can be deduced from the first approximation. The relation between the chemical shifts and the temperature are shown in Fig. 4. The chemical shifts show small but definite changes within the range of 1.5—3.0 Hz at the temperature of 34—*ca.* 150°C. The change in chemical shifts is linearly correlated with the temperature.

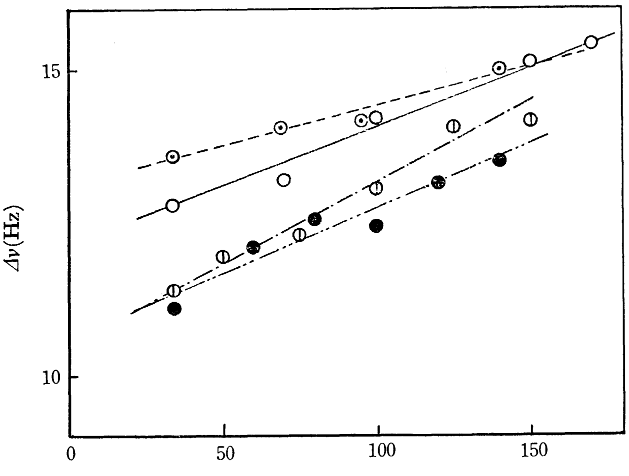
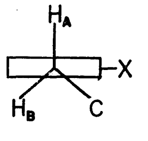
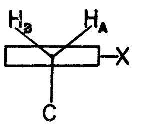


Fig. 4. Temperature dependence of the chemical shift difference between the benzylic methylene protons in IV$_{12}$—IV$_{15}$.
—○—; IV$_{12}$, ---⊙---; IV$_{13}$, --Φ--; IV$_{14}$, ---●---; IV$_{15}$

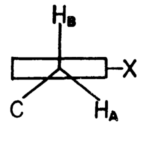
Such a temperature dependence may, in general, be attributed to solvation effects or the population effects. If the reasons for the temperature dependence of the spectra are attributed to the population effect, there will be two cases to be considered. The first is the isomeric conformations caused by the rotation about the C_α–C_{CO} bond, and the second is the change in the populations of the conformers (IX, X, and XI) formed by the rotation about the C_{ar}–C_α bond.



IX



X



XI

However, the change in population is not the likely cause of the change in chemical shifts. The change in population of the conformers on raising the temperature causes the averaging tendency of the signals, since the more unstable conformers increase in their populations. The data in Fig. 4 show, however, that the chemical shift differences between the A and B protons, rather, increase at higher temperatures.

Thus, the solvation effect becomes a more likely reason. Since, at lower temperatures, the solvated molecules reside close to the solute molecule for a longer time, the protons suffer from the anisotropy effects of various bonds and atoms. However, at higher temperatures, the effects will be more or less averaged out because of the faster motion of the molecules. These

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13) J. A. Pople, W. G. Schneider, and H. J. Bernstein, "High-Resolution Nuclear Magnetic Resonance," McGraw-Hill Book Co., Inc., New York (1959); J. W. Emsley, J. Feeny, and C. H. Sutcliff, "High Resolution Nuclear Magnetic Resonance Spectroscopy", Pergamon Press (1965).

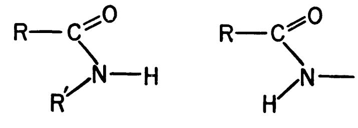
14) The apparent singlet signal may be the results of the accidental identity of the chemical shifts of the two benzylic protons in this solution system. Since the attempts to obtain spectra at low temperatures in other solvent systems have failed due to the poor solubility of the compound, we tentatively assume that the apparent singlet signal shows the fast exchange of the two ptorons. Incidentally, the corresponding diester compound has shown the splitting tendency of the singlet signal into a quartet at *ca.* −50°C in CH_2Cl_2–$CDCl_3$ (an unpublished work).

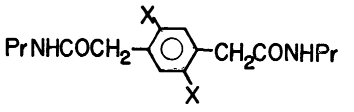
15) G. Binsch and J. D. Roberts, *J. Amer. Chem. Soc.*, **87**, 5157 (1965).

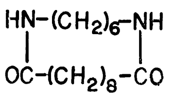
16) A. C. Cope, K. Banholzer, H. Keller, B. A. Pawson, J. J. Whang, and H. J. S. Winkler, *ibid.*, **87**, 3644 (1965).

differences should be able to cause the variation in chemical shifts to some extent.

The Conformations of the Amide Groups. It has been well documented that some amides exist as *s-cis* (XII) and *s-trans* (XIII) isomers. Lactams of the small rings cannot take the *s-trans* conformation due to the ring strain and exist solely as the *s-cis* conformation, whereas the open-chain amide is the most stable when the *s-trans* conformation is taken. In view of these facts, it will be interesting to study whether the amide groups in these hetera-*p*-carbophanes take the *s-cis* or the *s-trans* conformation. Thus, the N–H stretching absorption spectra, which have been extensively employed for the diagnosis of the conformation in question, have been examined in detail. The results obtained with dilute chloroform solutions are shown in Table 2, together with the data of the open-chain analogs (XIV and XV) and a simpler cyclic amide (XVI).


XII XIII


XIV(X=H)
XV (X=Me)



$$\begin{array}{l}\mathrm{HN{-}(CH_2)_6{-}NH}\\ \mathrm{OC{-}(CH_2)_8{-}CO}\end{array}$$

XVI

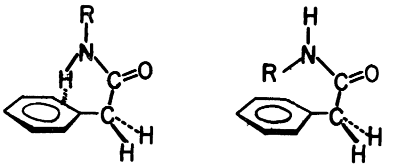
TABLE 2. ABSORPTION MAXIMA DUE TO N–H STERTCHING VIBRATION OF HETERA-*p*-CARBOPHANES AND RELATED COMPOUNDS IN $CHCl_3$ (cm^{-1})

Compound	*s-trans* (ε_{max})	*s-cis* or N–H···π interacting (ε_{max})
III_{12}		3436 (277)
IV_{12}		3433 (423)
III_{13}		3436 (171)
IV_{13}		3431 (259)
III_{14}		3437 (251)
IV_{14}		3433 (244)
III_{15}		3440 (267)
IV_{15}		3432 (188)
III_{16}		3439 (181)
IV_{16}		3431 (161)
XIV[a)]	3453 (133)	3437 (223)
XV[a)]	3449 (64)	3427 (192)
XVI	3453 (252)	

a) Graphically resolved.

As may be seen in the table, the hetera-*p*-carbophanes examined all show only one N–H stretching absorption, as does the dilactam (XVI), whereas the open-chain analogs (XIV and XV) show two ν_{NH} absorptions. The absorption of the dilactam (3453 cm^{-1}) corresponds to the frequencies of the well-documented *s-trans* conformation, and this compound is believed to exist as a bis-*s-trans* conformer.

The absorption frequencies of the hetera-*p*-carbophanes are rather low and are in the region of the *s-cis* conformation. However, the phenylacetamide derivatives are known to possess an internal N–H···π interaction[17)] which causes a lowering of the absorption frequencies, even though the conformation is *s-trans*. Indeed, the N–H absorptions of the open-chain analogs at the lower frequencies must be attributed to the N–H···π interacting species, since the absorption coefficients of the lower band are too large to assign to the *s-cis* conformation.


N–H···π intracting (*s-trans*) *s-cis*

Then a problem arises: why does the absorption appear at lower frequencies for the hetera-*p*-carbophanes? Is this a sign of an *s-cis* conformation or of N–H···π interaction? We would like to attribute the phenomena to the *s-cis* conformation of the amide groups for the following three reasons.

The first reason is the rigidity of the scale models. In the smaller ring compounds, although it is possible to make a model involving two *s-trans* conformations, this model tends to collapse when the support is removed, suggesting that this conformation has a high energy. It is also possible to make up a model involving *s-cis* and *s-trans* conformations. However, all the III_n and IV_n give only one absorption at about the same wave number, a number which is within the region attributable to the *s-cis* conformation. Therefore, a conformation involving the two *s-cis* amides is the more likely possibility.

The second reason is the consideration of the N–H···π interaction. The most favorable conformation for the interaction is the one in which the C_α–C_{CO} bond is perpendicular to the benzene ring (X); in this conformation, the N–H group approaches the π-lobe of the benzene ring from the top, and this gives the maximum overlap of the orbitals concerned. If the other conformations (*e.g.*, IX and XI) are taken and the overlap of the orbitals is decreased, the compound should show other N–H absorptions; these may be either free or interacting to a lesser extent. However, none of the hetera-*p*-carbophanes shows a second N–H band. Therefore, although this evidence is negative in nature, this can be taken as supporting the absence of the *s-trans* conformation.

The third reason is the evidence obtained by NMR spectroscopy. If there is an exchange between the *s-cis* and N–H···π interacting *s-trans* conformations, then there will be a change in the chemical shifts of the CH_2 protons, α to the nitrogen atom, since it is a well-

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[17)] I. Suzuki, M. Tsuboi, and T. Shimanouchi, *Spectrochim. Acta*, **16**, 467 (1960).

known fact that the *s-cis* and *s-trans* amides give signals characteristic of their conformations and that, even though these conformations are not detected by NMR because of the fast rate of exchange, there should yet appear a change in the chemical shifts. However, in reality, no change in the chemical shifts of the CH_2N signals was observed.

The presence of the *s-cis* conformation only for III_n and IV_n, in contrast to the presence of *s-trans* for the dilactam XVI, is undoubtedly a reflection of the rigidity of the benzene ring in III and IV, which limits the conformation of the molecule.