

BULLETIN OF THE CHEMICAL SOCIETY OF JAPAN VOL. 40 130—134 (1967)

Studies of the Model Compounds of Cyclopolymers.
An NMR Spectroscopic Study of cis and trans Isomers
of 2, 5-Dimethoxytetrahydrofuran*¹

Yuzo AITO, Taku MATSUO and Chuji Aso

Department of Organic Synthesis, Faculty of Engineering, Kyushu University, Fukuoka

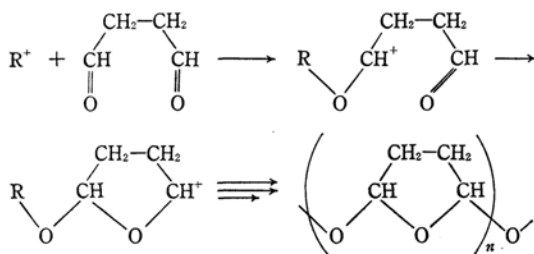
(Received December 7, 1965)

The configurational isomers of 2, 5-dimethoxytetrahydrofuran were synthesized as model compounds of the cyclopolymer of succinaldehyde. The NMR spectra of the isomers were then studied in carbon tetrachloride and in benzene. From the behavior of the methyl and methylene protons of the isomers in chemical shifts and in the formation of a "loose-complex" with benzene, it was concluded that the isomer with the lower boiling point had a trans configuration and that the isomer with the higher boiling point had a cis configuration. The NMR spectrum of 2, 5-dimethoxy-2, 5-dihydrofuran was similarly investigated in order to compare it with that of 2, 5-dimethoxytetrahydrofuran. The spectrum was rather simple; each signal was assigned to the cis or to the trans configurational isomer.

Previously, two of the present authors found that cyclopolymerization took place in the ionic polymerization of succinaldehyde,¹⁾ as is shown below:

*¹ Contribution No. 100 from the Department of Organic Synthesis, Faculty of Engineering, Kyushu University, Fukuoka.

1) C. Aso, A. Furuta and Y. Aito, *Makromol. Chem.*, **84**, 126 (1965).



The recurring unit of this polymer consists of a tetrahydrofuran ring with two C-O exocyclic bonds attached at the 2- and 5-positions. Axial and/or equatorial positions may be assumed by these C-O bonds analogously to the case of cyclopentane;²⁾ therefore, the formation of cis and trans configurations may be expected in the polymer chain. In order to establish the structure of this cyclopolymer, its infrared and NMR spectra were compared with those of two stereo-isomers of 2,5-dimethoxytetrahydrofuran.³⁾

These isomers have previously been prepared by Nielsen *et al.*, and their boiling points and refractive indices were compared.⁴⁾ However, their configurations were not assigned. More recently, some 3,4-disubstituted-2,5-dimethoxytetrahydrofurans were prepared and their configurations were investigated on the basis of NMR spectroscopic analysis.⁵⁾

In this paper, the authors intend to establish the assignment of the isomers mainly by a study of the NMR spectra.

Experimental

2,5-Dimethoxy-2,5-dihydrofuran was prepared by the bromination of furan, followed by solvolysis with methanol.^{6,7)} bp 53.5–54.5°C/15 mmHg; n_D^{25} , 1.4325.

Found: C, 55.48; H, 7.57%. Calcd for $\text{C}_6\text{H}_{10}\text{O}_3$: C, 55.37; H, 7.75%.

The gas chromatogram of this compound consists of a peak with a weak shoulder at the longer retention time. The NMR spectrum of this mixture of isomers was measured.*2

2,5-Dimethoxytetrahydrofuran was obtained by the

2) M. S. Newman, "Steric Effects in Organic Chemistry," John Wiley & Sons; Maruzen Co., Ltd., Tokyo (1956), p. 36.

3) C. Aso, Y. Aito and A. Furuta, presented at the 14th Discussion Meeting of the High Polymer Society of Japan (October, 1965).

4) J. T. Nielsen, N. Elming and N. Clauson-Kaas, *Acta Chem. Scand.*, **12**, 63 (1958).

5) D. Gagnaire and P. Vottero, *Bull. Soc. Chim. France*, **1963**, 2779.

6) J. Fakstorp, D. Raleigh and L. B. Schniepp, *J. Am. Chem. Soc.*, **72**, 869 (1950).

7) D. M. Burness, "Organic Syntheses," Vol. 40, p. 29 (1960).

*2 Two isomers were isolated by the use of a spinning band column in the cases of both 2,5-diethoxy-2,5-dihydrofuran and 2,5-di-*n*-butoxy-2,5-dihydrofuran. Their cis and trans configurations were estimated by means of a study of the NMR spectrum.⁸⁾

8) C. Aso and M. Miura, unpublished work.

catalytic hydrogenation of 2,5-dimethoxy-2,5-dihydrofuran. bp 128.0–134.0°C.

Found: C, 54.57; H, 9.20%. Calcd for $\text{C}_6\text{H}_{12}\text{O}_3$: C, 54.53; H, 9.15%.

Since the gas chromatogram of this compound consisted of two peaks, the existence of two isomers was expected. Therefore, the mixture was fractionated through a spinning band column; two fractions were thus obtained, each of which was almost a pure isomeric component. (I, the fraction with the lower boiling point; II, the fraction with the higher boiling point.) Some properties of these isomers are listed in Table I. The dipole moments listed in the table have been calculated from the dielectric constants of the isomers in a benzene solution at $25.00 \pm 0.01^\circ\text{C}$.

NMR measurements were made by a Varian Model A-60 spectrometer (60 Mc) at room temperature either in a carbon tetrachloride solution or in a benzene solution containing tetramethylsilane as an internal reference.

TABLE I. SOME PROPERTIES OF ISOMERS, I AND II, OF 2,5-DIMETHOXYTETRAHYDROFURAN

Property	I	II
Boiling point, $^\circ\text{C}$	130.0	134.0
Refractive index, n_D^{25}	1.4175	1.4160
Density, d_4^{25}	1.0192	1.0178
Molecular refraction ^{a)}	32.66	32.58
Dipole moment, ^{b)} Debye unit	2.2	2.4
Elemental analysis ^{c)} C, %	54.57	54.59
H, %	9.27	9.31

a) A value calculated by the summation of bond moments is 32.65, where an assumption is made that all C-O bonds contained in this compound are acetal C-O. If C-O bonds are assumed to consist of four acetal C-O and two ethereal C-O, the value becomes 32.81.

b) These values were calculated from dielectric constants of the isomers in benzene solution.

c) Calculated value: C, 54.53; H, 9.15%.

Results and Discussion

It is not clear whether the conformation of 2,5-dimethoxytetrahydrofuran is a half-chair or an envelope form. If the half-chair form is more stable, as has been indicated by Eliel for some five-membered, heterocyclic compounds⁹⁾ and by Gagnaire *et al.* for 3,4-disubstituted 2,5-dimethoxytetrahydrofuran,⁵⁾ the configurations of the cis and the trans isomers are as shown in Fig. 1(A). The envelope form, however, should also be taken into consideration, since the transformation from the half-chair to the envelope form is known to take place easily through pseudorotation in tetrahydrofuran.¹⁰⁾ The configurations of the isomers in the envelope form are summarized in Fig.

9) E. L. Eliel, "The Stereochemistry of Carbon Compounds," McGraw-Hill Book Co., New York (1962), p. 251.

10) W. J. Lafferty, D. W. Robinson and R. V. St. Louis, *J. Chem. Phys.*, **42**, 2915 (1965).

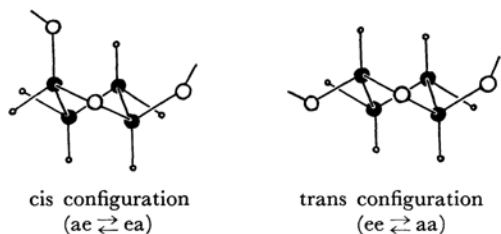


Fig. 1(A). Configurational isomers of 2,5-dimethoxytetrahydrofuran in half chair forms.
(○: oxygen, ●: carbon, ○: hydrogen)

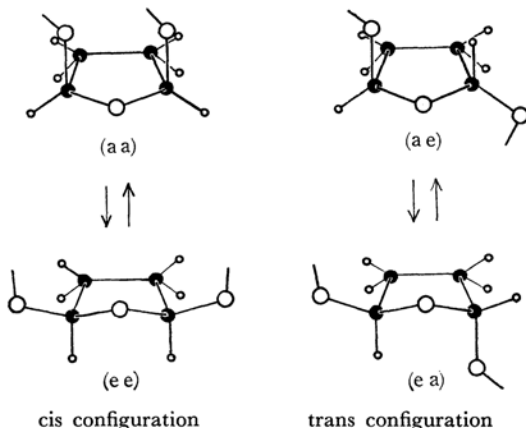


Fig. 1(B). Configurational isomers of 2,5-dimethoxytetrahydrofuran in envelope forms.
(○: oxygen, ●: carbon, ○: hydrogen)

1(B). The true situation may be defined as an equilibrium mixture of all the configurations in Fig. 1. In all of these configurations, the methoxy group is assumed to be freely rotating around the exocyclic C—O bond.

In the proton magnetic resonance of this compound, it is expected that the influence of methoxy oxygens on the neighboring protons is different between the cis and the trans configurations. Therefore, the chemical shifts will be different between cis and trans isomers. Figure 2 shows the NMR spectra of the isomers, I and II, of 2,5-dimethoxytetrahydrofuran in carbon tetrachloride and in benzene, while the chemical shifts are summarized in Table 2.

The methyl protons of I resonate at a little higher magnetic field than those of II. It may

TABLE 2. CHEMICAL SHIFTS (δ -VALUE, ppm) OF ISOMERS, I AND II, OF 2,5-DIMETHOXYTETRAHYDROFURAN

Assignment	I		II	
	in CCl ₄	in C ₆ H ₆	in CCl ₄	in C ₆ H ₆
Methylene protons	1.7—2.1	1.7—2.0	1.91	{1.70 1.88
Methyl protons	3.28	3.26	3.31	3.31
Methine protons	4.98	5.01	4.95	4.94

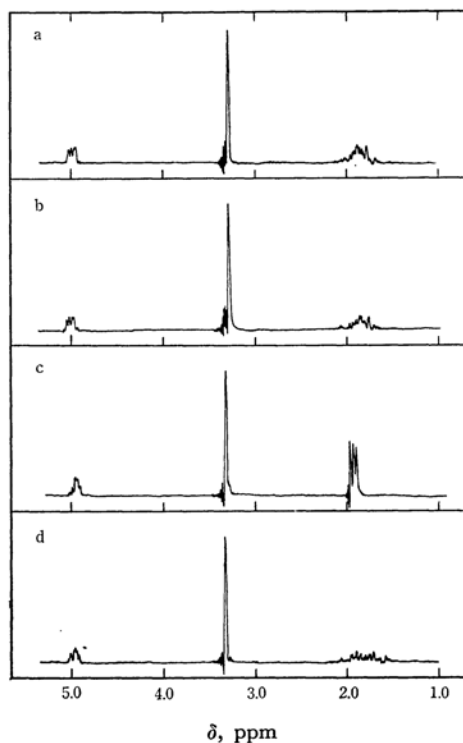


Fig. 2. NMR spectra of isomer I and II of 2,5-dimethoxytetrahydrofuran.

- a: Isomer I in carbon tetrachloride
b: Isomer I in benzene
c: Isomer II in carbon tetrachloride
d: Isomer II in benzene

easily be understood, by using a three-dimensional molecular model, that the probability of the methyl protons of a methoxy group approaching the other methoxy oxygen is much larger in the cis configuration than in the trans configuration. Since the methyl protons of the methoxy group are more or less positively charged, a weak interaction may be expected between the methyl protons and the electron-rich methoxy oxygen at a close distance. This interaction is expected to be a kind of weak hydrogen bonding, and it may be included in the dispersion interaction. Such an interaction is well known to cause a low field shift of the resonance signal of the proton involved in the interaction. Therefore, the methyl protons of the cis isomer are expected to resonate at a lower field than those of the trans isomer. For this reason, we suggest that the cis configuration may be assigned to II, whose methyl signal appears at a little lower field than that of I.

As to the methylene protons in carbon tetrachloride, I presents a complicated signal at about 1.9 ppm (Fig. 2a) and II shows a triplet at 1.91 ppm (Fig. 2c). This apparent difference in the signals comes from the differences both in the

chemical shifts and in the spin-spin coupling constants among the methylene protons.

In a benzene solution, methylene protons of I hardly show any difference from those in carbon tetrachloride (Fig. 2b). The methylene protons of II, however, present a complicated but almost symmetrical signal, shown in Fig. 2d, indicating that the methylene protons of II are markedly influenced by the variation in the solvent. This anomalous effect may be explained by the formation of a "loose-complex" between benzene and the methylene moiety. In the case of the trans configuration, two methoxy groups extend a large steric hindrance to the approaching benzene both above and below the plane of the molecule. The situation is much improved in the cis configuration, where only one site of the molecular plane is covered with methoxy groups. Therefore, the other site of the plane is free for the access of benzene for complex formation and larger diamagnetic shifts result, because of the magnetic anisotropy of benzene, on the two methylene protons closer to the benzene ring.

These considerations lead to the following explanation of the unusual solvent effect of benzene: II takes the cis configuration, and I the trans configuration, where methoxy groups hinder the complex formation with benzene and, therefore, no observable effects are expected on the chemical shifts of methylene protons. These assignments of the configurations are in agreement with those obtained from the chemical shifts of methyl protons described above. The true nature of the formation of a "loose-complex" is not obvious at present. Since the methylene groups are not directly bonded to the oxygen atom, no appreciable positive charge is expected on the methylene carbon. Therefore, it is unlikely that the protons are coordinated to the π electron cloud of the benzene molecule through the hydrogen bonding, as has been suggested in the case of chloroform. The situation may be, rather, that the benzene molecules tend to avoid the electron-rich center (oxygen in this case), as has been pointed out by Hutton and Schaefer,¹¹⁾ and associate preferably with the near-by non polar groups (methylene in the case under discussion) of the solute molecule. No matter what the nature of the "loose-complex," the methylene groups behave as if they have an apparent affinity to the benzene molecule. Considering this affinity, and also the steric hindrance discussed before, a possible model of the "loose complex" may be suggested as follows. The benzene molecule approaches the solute from above, or below the plane of the tetrahydrofuran ring, avoiding the freely-rotating methoxy group, until it reaches a location closer to the methylene groups

than to the oxygen atoms. These speculations are supported by the fact that no appreciable effect of benzene is observed on the chemical shifts of the methine proton, which is not only surrounded by oxygen atoms but which is also easily shielded, sterically, by the near-by methyl groups.

The NMR spectrum of 2,5-dimethoxy-2,5-dihydrofuran was also investigated in order to compare it with that of 2,5-dimethoxytetrahydrofuran. Recently, Gagnaire *et al.* showed the cis and trans configurations of the above dihydrofuran by means of a study of its NMR spectrum.⁵⁾ In that case, measurement was made in carbon tetrachloride and the assignment was based on the effect of the oxygen of the methoxy group on methine protons and on the spectra of 3,4-disubstituted-2,5-dimethoxytetrahydrofuran obtained from 2,5-dimethoxy-2,5-dihydrofuran.

The present authors obtained the NMR spectrum of 2,5-dimethoxy-2,5-dihydrofuran in benzene as well as in carbon tetrachloride, and they investigated the solvent effect and the magnetic anisotropy of the carbon-carbon double bond in the dihydrofuran ring. Figure 3 shows the NMR spectrum while the chemical shifts are summarized in Table 3. The sample used in this measurement is a mixture of two isomers, but the spectrum

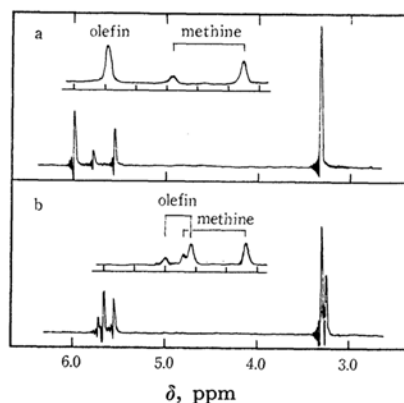


Fig. 3. NMR spectra of 2,5-dimethoxy-2,5-dihydrofuran (inserted spectra recorded in expanded scale).

a: in carbon tetrachloride
b: in benzene

TABLE 3. CHEMICAL SHIFTS (δ -VALUE, ppm)
OF 2,5-DIMETHOXY-2,5-DIHYDROFURAN

Assignment	Solvent		Configuration of isomer
	CCl ₄	C ₆ H ₆	
Methyl protons	3.33	{3.24 3.29	trans cis
Methine protons	{5.55 5.78	{5.54 5.74	cis trans
Olefinic protons	5.99	{5.72 5.80	cis trans

11) H. M. Hutton and T. P. Schaefer, *Can. J. Chem.*, **41**, 1857 (1963).

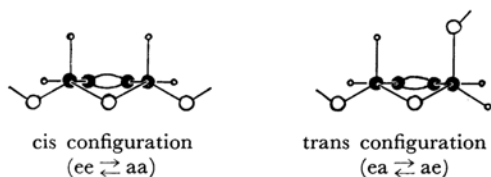


Fig. 4. Configurational isomers of 2,5-dimethoxy-2,5-dihydrofuran.

(○: oxygen, ●: carbon, ○: hydrogen)

is much more simple than that of the tetrahydrofuran derivative mentioned above.

The two olefinic protons lie on the same plane as the four ring carbon atoms, as is shown in Fig. 4. The interaction of these protons with the methoxy oxygen is very small; also, the spin-spin coupling between the olefinic proton and the methine proton is negligibly small. Only one singlet peak is observed, for these protons, at 5.99 ppm in carbon tetrachloride (Fig. 3a). However, in the benzene solution, the signal of olefinic protons is split into two peaks. It is evident from the expanded spectrum (Fig. 3b) that the olefinic proton shows two peaks, at 5.72 ppm (cis) and at 5.80 ppm (trans). This behavior of olefinic protons upon the variation in the solvent may be explained by the fact that the steric hindrance of two methoxy substituents for the formation of a "loose-complex" with benzene is quite different between cis and trans configurations, as has been mentioned in the case of the tetrahydrofuran derivative.

On the other hand, methine protons show two peaks, at 5.55 and 5.78 ppm, in carbon tetrachloride. These two peaks must correspond to the peaks of the cis and trans isomers derived from the difference in the configurations of the two methoxy substituents.

Therefore, the signal of the methine protons of the cis (ee) configuration (Fig. 4), which is considered to be more stable than the cis (aa) con-

figuration due to the steric hindrance between the two methoxy groups, may be expected to appear at a higher magnetic field as a direct effect of the magnetic anisotropy of the carbon-carbon double bond. However, the methine protons of the trans configuration ($ea \rightleftharpoons ae$) are affected by the diamagnetic field of the carbon-carbon double bond to a lesser extent than in the case of the cis configuration. Consequently, in the spectrum of Fig. 3a, the peak at 5.55 ppm should be assigned to the methine proton of the cis isomer, and the peak at 5.78 ppm to those of the trans isomer. These conclusions agree with those of Gagnaire *et al.*⁵⁾

The ratio of the cis to the trans isomer of the dihydrofuran derivative (about 7/3), as estimated from the intensities of the NMR peaks, was in agreement with that of the unfractionated tetrahydrofuran derivative. This indicates that the isomerization cannot take place during the catalytic hydrogenation of 2,5-dimethoxy-2,5-dihydrofuran.

As has been mentioned above, NMR spectroscopic analysis makes it possible to identify the configurational isomers of 2,5-dimethoxytetrahydrofuran and 2,5-dimethoxy-2,5-dihydrofuran. The stereochemical structure of polysuccinaldehyde is now being investigated on the basis of NMR and infrared spectroscopic information; it will be reported on at a later date.

The present study was supported by a grant-in-aid for scientific research from the Ministry of Education.

The authors wish to express their thanks to Professor Tetsuro Seiyama for affording the facilities for measuring the dielectric constants. Thanks are also due to Mr. Akio Furuta and Mr. Masanobu Miura for their help in preparing the model compounds, and to Mr. Yusuke Nakayama for his measurements of the NMR spectra.