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Determination of Some Tertiary Amines as π-Complexes with Tetracyanoethylene

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Some tertiary amines were determined by measurement of the absorbance of their π-complex (I) with tetracyanoethylene (TCNE) as a function of time. The initial absorbance values of I formed (corresponding to the added concentrations of tertiary amines) were calculated by a numerical method with a pseudo first-order rate equation for the decomposition of I using the rate constant and the absorbance values as a function of time. Calibration plots gave good straight lines for each tertiary amine. The average errors of determination were from −1.23% to +3.03% and the relative standard deviations were less than 1.82% ($n=3$). The recovery of each amine was from 98.0% to 103.0%. For mixtures of primary, secondary and tertiary amines, the interference of primary and secondary amines could be eliminated by addition of acetic anhydride before the reaction with TCNE. The average errors of determination were from −2.96% to +5.79% and the relative standard deviations were less than 1.15% ($n=3$). The recovery of each tertiary amine was from 97.0% to 105.8%. The presented method is accurate, rapid and highly sensitive for many tertiary amines.

Keywords——tertiary amines; tetracyanoethylene; decomposition of π-complex; pseudo first-order reaction; numerical method; removal of primary and secondary amines

Colorimetric procedures have been used extensively in primary and secondary amine analysis, but there are few reported examples of the determination of tertiary amines.[2] Tetracyanoethylene (TCNE) is a useful reagent which reacts rapidly and quantitatively with a large number of aromatic compounds under mild conditions.[3] However, the equilibrium method for the determination of most tertiary amines with TCNE is not available, mainly because the π-complex (I) formed is unstable in favor of the corresponding tricyanovinyl derivative (III), probably with the participation of the σ-complex (II) as an intermediate (Chart 1).[4] Schenk *et al.*[5] first reported the colorimetric determination of some tertiary amines with TCNE. They utilized acetic anhydride in order to retard the decomposition of I. However, acetic acid in the acetic anhydride used produced hypochromatic effects with I, and the analysis procedure was somewhat time-consuming. This paper describes an accurate and rapid method based on a kinetic approach for the determination of some tertiary amines by complexation

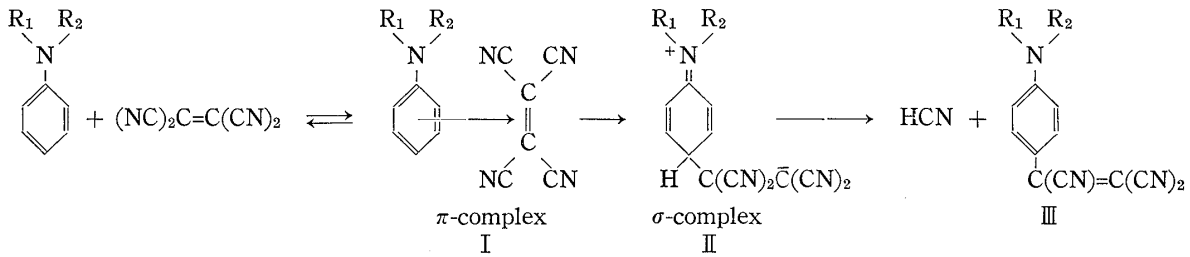

Chart 1

1) Location: 5, *Nakauchi-cho, Yamashina-ku, Kyoto 607, Japan.*
2) F.E. Critchfield and J.E. Ruch, "Treatise on Analytical Chemistry," Vol. 15, Part II, ed. by I.M. Kolthoff and P.J.E. Elving, A Wiley-Interscience Publication, New York, 1976, p. 179.
3) D.N. Dhar, *Chem. Rev.*, **67**, 611 (1967).
4) Z. Rappoport and E. Shohamy, *J. Chem. Soc.* (*B*), **1969**, 77.
5) G.H. Schenk, P. Warner, and W. Bazzelle, *Anal. Chem.*, **38**, 907 (1966).

with TCNE in the presence or absence of primary and secondary amines. The presented method is more sensitive and reproducible than the method employed by Schenk *et al.*

Experimental

Materials——TCNE and amines were obtained commercially. TCNE was purified by repeated sublimations *in vacuo* (120°/4 mm) and a fresh solution was prepared daily by dissolving the compound in methanol–dichloromethane mixture. Antipyrin and other pharmaceuticals were of Japanese Pharmacopeia (JP) IX grade, and stock solutions were prepared according to the method given in JP VII. All other amines were purified by distillation after treatment with potassium hydroxide pellets and the stock solutions were prepared by dissolving weighed amounts of the amines in dichloromethane. Acetic anhydride (AA) used was of analytical reagent grade. The solvents used were purified by the usual techniques.

Apparatus——Absorption spectra were obtained and kinetic studies were carried out using a Shimadzu UV-350 spectrophotometer with 10 mm cells. The cell compartment was thermostated at $24\pm0.1°$ with circulating water.

Procedure——First, 1.0 ml of amine solution, 5.5 ml of TCNE solution and methanol were pipetted into a 10 ml volumetric flask. This was diluted with dichloromethane. A reference blank solution was prepared by the same procedure, but using dichloromethane instead of the sample solution. Absorbance was measured as a function of time against the blank solution at a suitable wavelength (see Table II). For samples containing primary or secondary amines, 1.0 ml of sample solution and 2.0 ml of 1.5 M AA solution were added and the mixture was allowed to stand for *ca.* 10 min, then the same procedures were carried out.

Calculation of the Initial Absorbance of I——For a first- or pseudo first-order reaction, the following equation holds:[6]

$$\ln(A_\pi - A_\sigma)/(A_t - A_\sigma) = k_1 \cdot t \qquad (1)$$

where A_π and A_t are the absorbances of I at any wavelength corresponding to time zero and time t, respectively, A_σ is the final absorbance of II at the same wavelength, and k_1 is the rate constant. A_π at any concentration of tertiary amine could be calculated by a numerical method based on Eq. (1), given k_1 and A_t as a function of time, provided that the concentration of I is proportional to that of tertiary amine.[7,8]

Results and Discussion

The fast conversion of I into II and the slow formation of III can be explained by assuming that II, which is rate-determining for the overall reaction, is very stable. The high stability of II may be correlated with the unusually low activation energy and the high negative entropy of the transition between I and II (Table I).

Table I. Thermodynamic Activation Parameters for the Conversion of I into II in Methanol–Dichloromethane Mixtures[a]

Methanol % (v/v)	5.0	8.0	10.0	15.0	20.0
E_a (kcal/mol)[b]	5.21	4.97	4.33	4.28	3.39
ΔS (e.u.)[b]	−53.2	−57.7	−59.4	−60.0	−62.3

a) The solutions contained $[TCNE]_0 = 5.5\times10^{-2}$ M and $[N,N\text{-dimethylaniline}]_0 = 1.25\times10^{-3}$ M.
b) E_a and ΔS were calculated from the kinetic data at 15°, 20° and 25.5° (A.E. Frost and R.G. Pearson, "Kinetics and Mechanism," John Wiley and Sons, Inc., New York, 1961, p. 77).

The rate equations for the formation of II from I and of III from II are given by Eqs. (2) and (3), respectively.[9]

$$d[II]/dt = k_2[I][amine] \qquad (2)$$

$$d[III]/dt = k_2'[II][amine] \qquad (3)$$

where [I], [II], [III], and [amine] are the concentrations of I, II, III, and tertiary amine

6) J.F. Bunnett, "Techniques of Chemistry: Investigation of Rates and Mechanisms of Reactions," Vol. 6, ed. by E.S. Lewis, A Wiley-Interscience Publication, New York, 1974, p. 137.
7) R.P. Brent, "Algorithms for Minimization without Derivatives," Prentice-Hall, Englewood Cliffs, 1973, p. 1.
8) H.L. Pardue, "Advances in Analytical Chemistry and Instrumentation," Vol. 7, ed. by C.N. Reilley and F.W. McLafferty, A Wiley-Interscience Publication, New York, 1968, p. 141.
9) *a*) Z. Rappoport, *J. Chem. Soc.*, **1963**, 4498; *b*) Z. Rappoport and A. Horowitz, *ibid.*, **1964**, 1348.

at any time, and k_2 and k_2' are the second-order constants. Since most tertiary amines reacted nearly quantitatively with TCNE under the conditions used, the concentration of free tertiary amine can be neglected in the presence of excess of TCNE. The rate of formation of II, which is equal to that of decomposition of I, then depends only on the concentration of I formed. As shown in Fig. 1, when the concentration of TCNE was 20 times or more greater than that of tertiary amine, the rate of decomposition of I followed first-order kinetics [where $(A_\infty - x)$ is the concentration of I at time t].

As the rate of conversion of I into II was very rapid in polar media at room temperature, the solvents which were suitable were limited (polar solvents are most capable of dispersing the charges of I in the transition state, which involves partial cationic character for the amine and anionic character for the TCNE molecule, by specific solvation of the latter, as shown in Chart 2).[10] Dichloromethane has been utilized, but TCNE is poorly soluble in it at room temperature.[5,11] In the present work, 5.5% (v/v) methanol–dichloromethane mixture was used.

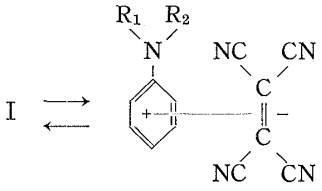

Chart 2

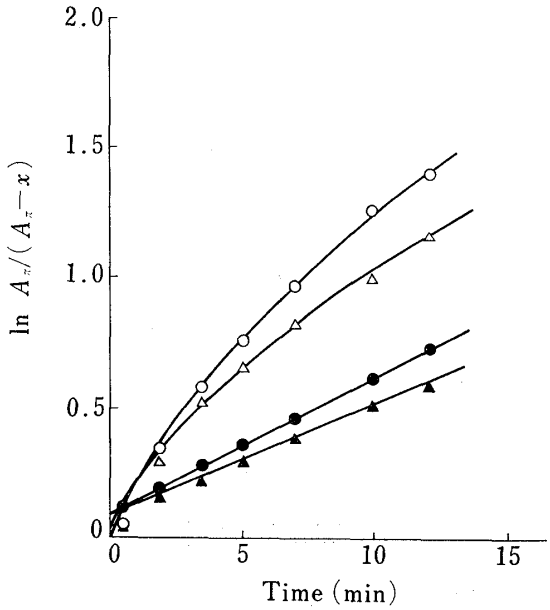

Fig. 1. Effect of TCNE Concentration on the Reaction Rate

—○—: 5.5×10^{-3} M, —▲—: 7.0×10^{-2} M, —△—: 1.1×10^{-2} M, —●—: 5.5×10^{-2} M. The solutions contained $[DMA]_0 = 2.75\times10^{-3}$ M in 5.5% (v/v) methanol–dichloromethane at 24°.

Table II. Determination of Tertiary Amines

Amine	λ (nm)	Amount present (μg/ml)	Amount found[a] (μg/ml)	Recovery (%)
N,N-Dimethylaniline	675	12.1	12.1±0.22	100.0
		18.2	18.2±0.06	100.0
		21.2	21.1±0.19	99.5
		24.3	24.0±0.35	98.8
		30.3	30.1±0.22	99.3
Antipyrine	530	18.8	18.7±0.34	99.5
		26.4	26.6±0.23	100.8
		37.7	37.3±0.41	98.9
Pyridine[b]	600	31.6	31.6±0.06	100.0
3,5-Lutidine	600	42.9	44.2±0.42	103.0
		64.3	65.6±0.24	102.0
2,4,6-Collidine[b]	600	24.3	24.0±0.17	98.8
		24.3	24.5±0.12	100.8
Tributylamine	590	74.1	75.6±0.26	102.0
		148.2	148.2±0.38	100.0

a) Values are the means ± SD of three determinations.
b) 20±0.1°.

10) R.S. Mulliken and W.B. Person, "Molecular Complexes," John Wiley and Sons, Inc., New York, 1969, p. 238.
11) N.S. Isaacs, *J. Chem. Soc.* (*B*), **1966**, 1053.

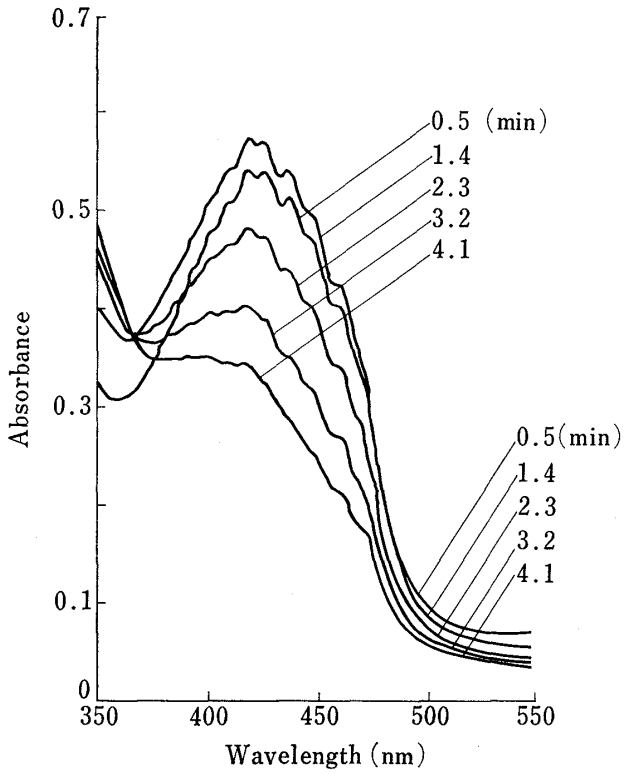

Fig. 2. Absorption Spectra Changes during the Reaction of Aminopyrin with TCNE in 1.0% (v/v) Methanol–Dichloromethane at 24°

Concentration: TCNE (5.5×10^{-2} M), aminopyrin (5.02×10^{-4} M).

Under the conditions given, good linear correlations were obtained between A_π and the concentrations of tertiary amines. The results of the analyses are summarized in Table II. In most cases the errors of determination (average of three trials) were from −1.23% to +3.03% and the relative standard deviation were less than 1.82% over the ranges tested. Some tertiary aliphatic amines were examined for reactivity with TCNE, although it has been reported that TCNE does not react with them. Tributylamine and triethylamine gave the corresponding I, though only tributylamine gave quantitative recoveries under these experimental conditions (Table II). The relative standard deviation for the determination of 74.1 μg/ml of tributylamine was 0.34% ($n=3$). Aminopyrin, amitriptyline, imipramine, chlorpromazine, dibucaine, diphenhydramine and promethazine could not be determined by the present method, because of the formation of TCNE anion radical ($TCNE^{\cdot-}$), which has many absorption peaks (λ_{max} 382, 390, 398, 407, 416, 425, 435, 445, 457, 468 nm), by one-electron reduction[12] (Fig. 2).

Table III. Determination of Tertiary Amines in the Presence of Primary or Secondary Amines

Mixture	Amount present (μg/ml)	Amount found[a] (μg/ml)	Recovery (%)
N,N-Dimethylaniline	48.4	51.2±0.43	105.8
N-Methylaniline	428.8		
	58.0	57.2±0.24	98.6
	385.6		
N,N-Dimethylaniline	121.2	121.6±0.24	100.3
Benzylmethylamine	484.8		
Antipyrine[b]	162.4	158.4±0.38	97.5
Diphenylamine	415.2		
Antipyrine[b]	253.2	251.2±0.40	99.2
2,5-Dimethoxyaniline	389.6		
3,5-Lutidine	94.4	93.6±1.08	99.2
Ethanolamine	610.8		
Tributylamine	74.0	77.2±0.39	104.3
Butylamine	292.4		
	170.4	168.4±1.12	98.8
	58.4		
Tributylamine	148.4	144.0±0.74	97.0
tert-Butylamine	58.9		

a) Values are the means ±SD of three determinations.
b) 1.0% (v/v) Methanol–dichloromethane mixture.

12) O.W. Webster, W. Mahler, and R.E. Benson, *J. Am. Chem. Soc.*, **84**, 3678 (1962).

Since TCNE reacts readily with many aromatic compounds, error may arise in the colorimetric determination of tertiary amines. Thus, the separation of tertiary amines from other compounds before analysis was necessary. The presence of more than 5 μg/ml of butylamine, *tert*-butylamine, ethanolamine, diphenylamine, benzylmethylamine, aniline, 2,5-dimethoxyaniline, *p*-anisidine and N-methylaniline (tested in this work) resulted in large errors. In general, it is well known that most primary and secondary amines react with AA without any catalyst at room temperature.[2] In practice, any of the primary or secondary amines at the concentrations listed in Table III could be completely removed by acetylation. However, as described by Schenk *et al.*,[13] AA would interfere by complexing with tertiary amines. The concentration of AA was plotted against the equilibrium constant, K, given by Eq. (4).[14]

$$K = [\mathrm{I}]/[\mathrm{TCNE}][\mathrm{amine}] \qquad (4)$$

Interference was observed in the range above 0.5 M. A hypochromatic effect on compound I of tertiary amines was observed with AA in the region above 0.3 M. In the present work, therefore, 0.3 M AA was used for acetylation.

Calibration curves were prepared from known concentrations of the tertiary amines containg 0.3M AA, and gave good straight lines. The results of analyses for tertiary amines in the presence of primary or secondary amines are shown in Table III. The errors of determination (average of three trials) were from −2.96% to +5.79% over the ranges given. The relative standard deviations were below 1.15% (n=3).

13) G.H. Schenk, P. Wines, and C. Mojzis, *Anal. Chem.*, **36**, 914 (1964).
14) R.H. Keefer and L.J. Andrews, *J. Am. Chem. Soc.*, **72**, 4677 (1950).