

calculated slopes at each point. Similar results were obtained by the two methods of obtaining the slope. During this iterative procedure, concentrations were calculated by numerical integration.

Another least-squares program, BESTFIT, was written to obtain the values for k_8 , k_9 , k_{10} , and K_{11} which would give the minimum squared relative difference between experimental and calculated k_{obsd} in eq 12.

Cycloaddition Reactions of Isocyanates. The Reaction of Aryl Isocyanates with N,N-Dimethylformamide

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Received April 26, 1968

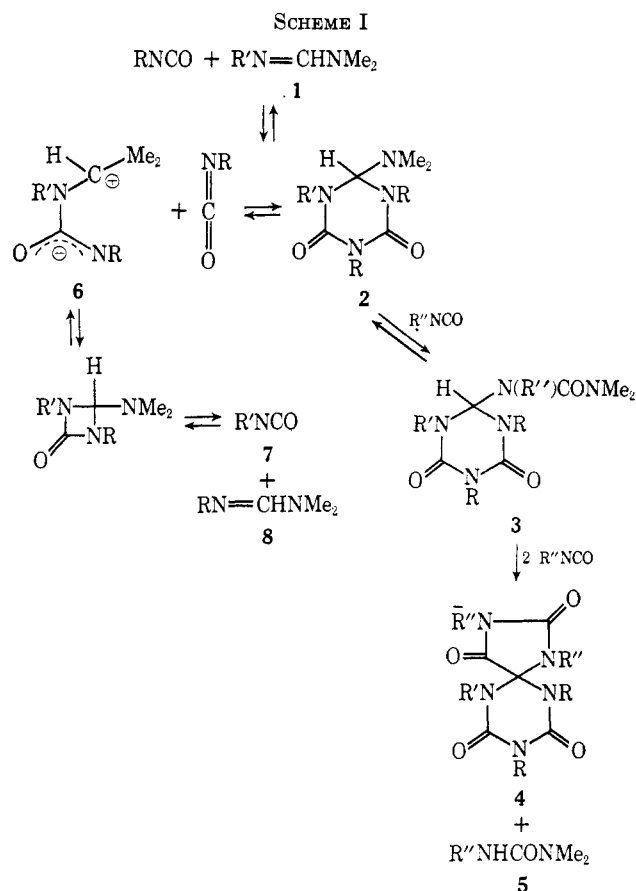
Heating aryl isocyanates in N,N-dimethylformamide produces the previously unreported pentaaryl-1,3,6,8,10-pentazaspiro[4.5]decane-2,4,7,9-tetraones **4**. The formation of **4** involves N-aryl-N'-dimethylformamidines **1** as well as the 2:1 cycloadducts **2** of aryl isocyanates and **1** as intermediates.

The reaction of aryl isocyanates with N,N-dimethylformamide (DMF) reportedly produces N-aryl-N'-dimethylformamidines (**1**)¹⁻³ or triaryl isocyanurates,³ the cyclic trimerization products of aryl isocyanates, depending upon the reaction conditions. In addition to 1 substantial amounts of high-melting solid materials are formed on heating equimolar quantities of aryl isocyanates and DMF at 150° (Table I). As discussed below, these products are assigned the spiro structure **4**.^{4,5}

The phenyl compound (**4**, R, R', R'' = C₆H₅) was also obtained when N-phenyl-N'-dimethylformamide (**1**, R' = C₆H₅) was heated with excess phenyl isocyanate (Scheme I). Thus, it is suggested that **1** is an intermediate in the formation of **4**. We have recently shown that 2:1 adducts can be obtained from arylsulfonyl isocyanates and C=N double bond containing substrates,⁶ and a similar reaction may account for the formation of **4**. When a mixture of 2 equiv of phenyl isocyanate and 1 equiv of **1** (R' = C₆H₅) is kept at room temperature for 5 days, a 78.5% yield of the 2:1 adduct **2** is obtained.⁷

The 2:1 adduct **2**, upon heating with 3 equiv of phenyl isocyanate, produces the spiro compound **4** and N-phenyl-N'-dimethylurea **5** (R'' = C₆H₅). Heating **2** (R, R' = C₆H₅) with *p*-tolyl isocyanate at 150° gives spiro compound **4** (R, R' = C₆H₅; R'' = 4-CH₃C₆H₄) in low yield. The structure of the mixed spiro compound follows from the nmr spectrum, which shows only two methyl signals at δ 2.22 and 2.42 ppm, and a relative intensity of methyl protons to aryl protons of 6:23.

The formation of the 2:1 adducts of aryl isocyanates and N-aryl-N'-dimethylformamidines indicates that the linear 1:1 adducts **6** can be intercepted by a second isocyanate molecule to afford **2**. As a side reaction cyclization of **6** can occur, as indicated by the isolation



of 1,2 cycloadducts and exchange products **7** and **8**. The latter are formed almost exclusively when the generated new isocyanate (R''NCO) is removed by distillation.⁸

The formation of the exchange products **7** and **8** leads to a great variety of products in the reaction of aryl isocyanates and N-aryl-N'-dimethylformamidines, in which both aryl groups are different. For example, **7** could intercept **6** or form a 1:1 adduct with the starting formamide. Likewise, **8** could form a 1:1 adduct with the starting isocyanate. In view of the ambident character of **6** and the possibility of addition across the C=N or C=O bond in the isocyanate, four isomeric 2:1 adducts are visualized, discounting the possibility

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(4) An asymmetric aryl isocyanate trimer structure was erroneously assigned to these compounds in the abstracts of the General Meeting of the Gesellschaft Deutscher Chemiker, 1967.⁴

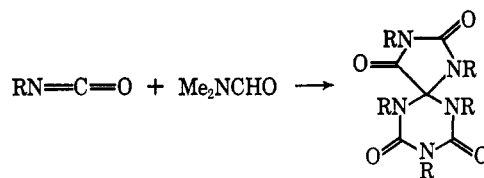
(5) H. Ulrich, *Angew. Chem. Intern. Ed., Engl.*, **6**, 1000 (1967).

(6) H. Ulrich, B. Tucker, and A. A. R. Sayigh, *J. Amer. Chem. Soc.*, **90**, 528 (1968).

(7) The formation of 2:1 adducts of phenyl isocyanate and N-phenyl-N'-dimethylformamide has also been observed by Dr. R. H. Richter of the Carnegie-Mellon University. We are grateful to Dr. Richter for communicating this information to us.

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TABLE I



R	Yield, %	Mp, °C	Empirical formula ^d	Calcd, %			Found, %		
				C	H	N	C	H	N
C ₆ H ₅	30.3	233-234 ^a	C ₃₅ H ₂₅ N ₅ O ₄	72.49	4.34	12.08	72.59	4.33	12.15
2-CH ₃ C ₆ H ₄	3.4	287-288 ^a	C ₄₀ H ₃₅ N ₅ O ₄	73.94	5.43	10.78	74.20	5.52	10.82
4-CH ₃ C ₆ H ₄	44.0	268-270 ^b	C ₄₀ H ₃₅ N ₅ O ₄	73.94	5.43	10.78	73.72	5.47	11.01
4-ClC ₆ H ₄	12.3	308 ^c	C ₃₅ H ₂₀ Cl ₅ N ₅ O ₄	55.91	2.68	9.31	56.12	2.84	9.35
4-BrC ₆ H ₄	21.0	319 ^a	C ₃₅ H ₂₀ Br ₅ N ₅ O ₄	43.15	2.07	7.18	43.41	2.32	6.94

^a Recrystallized from ethanol. ^b Recrystallized from ethyl acetate. ^c Recrystallized from chloroform-diethyl ether. ^d Respective registry numbers follow: 17350-46-8; 17397-63-6; 17397-64-7; 17397-65-8; 17397-66-9.

of interchange of the reagents. Of course, interception of the intermediate **6** by a second molecule of the formamidine can occur also giving rise to the formation of two isomeric 1:2 adducts.⁹⁻¹¹ The random distribution of products was noted in the reaction of **2** (R, R' = C₆H₅) with *p*-tolyl isocyanate, which produces mixtures of the expected reaction products as indicated by the mass spectrum of the crude mixture which shows in addition to the ion with *m/e* 607 the following molecular ions at 649, 635, 621, 593, and 579.

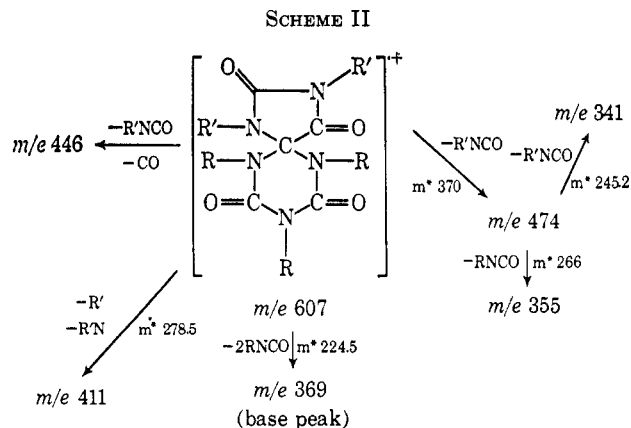
The possibility of formation of isomeric adducts makes structure elucidation of **2** (R, R' = C₆H₅), the precursor of **4** (R, R', R'' = C₆H₅), mandatory. The ir spectrum of **2** (R, R' = C₆H₅) shows two double-bond absorptions at 1701 and 1661 cm⁻¹, and the nmr spectrum shows in addition to aryl protons the dimethylamino group at δ 2.35 ppm and the methine proton at 5.93.

The mass spectrum of **2** (R, R' = C₆H₅) shows a molecular ion at *m/e* 386 and a base peak at 119, due to a phenyl isocyanate ion. The presence of an ion at 148 (Me₂NCH=NC₆H₅)⁺, a diphenyldiaziridine-dimethyliminium ion at 238, and the absence of a peak at 73 (dimethylformamide ion) eliminate two of the possible isomeric structures for the 2:1 adducts **2**.

Further reaction of **2** with aryl isocyanates could occur at the activated carbon atom to produce the intermediate **3** (Scheme I), which on subsequent reaction with isocyanate would form **4** and **5**. The reaction of isocyanates with orthoesters¹² and acetals¹³ to afford linear 1:1 adducts is well known. A similar sequence, involving cyclization, was observed by Brederick and his students¹⁴ in the reaction of *N,N*-dimethylformamide diethyl acetal and aryl isocyanates. In this reaction the five-membered ring diarylparabanic acid *O,N*-acetals and ethyl arylcarbamate were obtained.

The structural assignment of the spiro compounds (**4**) rests on spectral data. For example, the arrangement of the five-membered ring is indicated by ir spectroscopy. The low C=O absorption at 1786 cm⁻¹

is caused by the carbonyl group adjacent to the spiro carbon atom. This position agrees with the carbonyl absorption in other similar five-membered ring systems, such as 1,3-diphenylparabanic acid *O,N*-acetals (1780 cm⁻¹),¹⁵ and 1,3-diphenyl-5-acetyl-5-methylhydantoin (1779 cm⁻¹).¹⁶ The nmr spectrum of compound **4** (R, R', R'' = C₆H₅) shows only signals due to aromatic protons: a multiplet centered at δ 6.65 ppm integrating for two protons and a group of unresolved signals, 7.0-8.0, and equivalent to 23 H. The signals at high field can be assigned to two protons of a phenyl substituent in the five-membered ring. This shielding is attributed to the anisotropy of the magnetic susceptibility of the carbonyl groups and benzene rings in the six-membered ring. The mass spectrum shows a molecular ion at *m/e* 579, in accordance with the general formula C₃₅H₂₅N₅O₄, and the fragmentation pattern is in agreement with the spiro structure. The base peak is due to a fragment at 341. This ion is obtained by two degradations, one with the loss of a fragment at 238 and another with the successive elimination of two isocyanate molecules. The fragmentation sequences have been determined more specifically in the mass spectrum of **4** (R, R' = C₆H₅; R'' = CH₃C₆H₄) where fragmentation of the five- or the six-membered ring can be differentiated (Scheme II). Basic hydrolysis of **4** (R, R', R'' = C₆H₅) gave carbamylide and *N,N'*-diphenylformamidine.



(9) The formation of 2:1 and 1:2 adducts of azomethines and isocyanates¹⁰ and sulfonyl isocyanates¹¹ has been reported.

(10) D. Clemens and W. Emmons, *J. Org. Chem.*, **26**, 767 (1961).

(11) W. Bartmann, *Chem. Ber.*, **100**, 2938 (1967).

(12) H. von Brachel and R. Merten, *Angew. Chem. Intern. Ed. Engl.*, **1**, 592 (1962); H. Biener, *Ann.*, **686**, 102 (1965).

(13) H. Ulrich and A. A. R. Sayigh, *Angew. Chem. Intern. Ed. Engl.*, **5**, 844 (1966).

(14) H. Brederick, G. Simchen, and E. Göknel, *ibid.*, **3**, 704 (1964).

(15) We are indebted to Professor Brederick for communicating the carbonyl absorptions in diphenyl parabanic acid *O,N*-acetals.

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Experimental Section¹⁷**1,3,6,8,10-Pentaphenyl-1,3,6,8,10-pentazaspiro[4.5]decane-2,4,7,9-tetraone (4, R, R', R'' = C₆H₅).** **A. General Procedure.**

—The preparation of 4 (R, R', R'' = C₆H₅) exemplifies the procedure followed in the synthesis of the pentaaryl-pentazaspiro-decanetetraones listed in Table I. A mixture of 36.5 g (0.5 mol) of N,N-dimethylformamide and 59.5 g (0.5 mol) of phenyl isocyanate is heated at 150° for 150 min. Vacuum distillation affords 26 g (35%) of N-phenyl-N'-dimethylformamide, bp 124° (6 mm), and trituration of the residue with ethanol precipitates 21.9 g (30.3%) of 1,3,6,8,10-pentaphenyl-1,3,6,8,10-pentazaspiro[4.5]decane-2,4,7,9-tetraone (4, R, R', R'' = C₆H₅), mp 220–226°. A sample upon solution in concentrated H₂SO₄ and reprecipitation with water and subsequent recrystallization from ethanol showed a mp of 233–234°: ir (CHCl₃), 1786, 1724, 1685 cm⁻¹ (C=O); mass spectrum (70 eV) at *m/e* 579, major fragments at 460, 341, 210, 145, 119, 91, 77. The compound has a tendency to crystallize with 1 mol of ethanol, and vacuum drying is necessary to obtain an analytically pure sample. The yield of obtained reaction products is somewhat dependent upon the ratio of phenyl isocyanate to DMF. Using a ratio of 1:1.3, 46% of N-phenyl-N'-dimethylformamide and 43.5% of 4 (R, R', R'' = C₆H₅) is obtained.

B. From Phenyl Isocyanate and N-Phenyl-N'-dimethylformamide.—A mixture of 11.9 g (0.1 mol) of phenyl isocyanate and 7.4 g (0.05 mol) of 1 (R = C₆H₅) is heated at 150° for 4 hr. Trituration with diethyl ether and purification as in A affords 9.9 g (68.5%) of 4 (R, R', R'' = C₆H₅), mp 225–228°.

Hydrolysis with KOH/CH₃OH.—To a solution of 3.34 g of potassium hydroxide in 200 ml of methanol 8.6 g (0.015 mol) of 4 (R, R', R'' = C₆H₅) is added, and the mixture is refluxed for 18 hr. After cooling 2.25 g (26%) of the starting material, mp 225–228°, is removed by filtration. Evaporation of the solvent and addition of water to the residue precipitates 3 g of carbanilide,

(17) Analyses were by Schwarzkopf Microanalytical Laboratory, Woodside, New York. Ir spectra were determined using a Beckmann IR-8 spectrophotometer. Nmr spectra were obtained from samples in deuteriochloroform solution with a Varian A-60 instrument using tetramethylsilane as the internal standard. Mass spectra were determined using a MS 12 mass spectrograph.

mp 245–246°. Acidification of the filtrate precipitates 1.3 g of N,N'-diphenylformamide, mp 143–144° (lit.¹⁸ mp 143°) after recrystallization from ethanol.

2-Dimethylamino-1,3,5-triphenylhexahydro-1,3,5-triazine-4,6-dione (2, R, R' = C₆H₅).—A mixture of N,N-dimethyl-N'-phenylformamide (14.8 g, 0.1 mol) and phenyl isocyanate (23.8 g, 0.2 mol) was kept for 5 days at room temperature. Trituration with diethyl ether affords 28.9 g (78.5%) of 2-dimethylamino-1,3,5-triphenylhexahydro-1,3,5-triazine-4,6-dione, mp 164–168°, which melts at 179–180° after recrystallization from methanol: ir (CHCl₃) 1701, 1661 cm⁻¹ (C=O); mass spectrum (70 eV) *m/e* 386, 357, 342, 238, 148, 119, 106, 104, 91, 77.

Anal. Calcd for C₂₃H₂₂N₄O₂: C, 71.43; H, 5.73; N, 14.44. Found: C, 71.66; H, 5.68; N, 14.32.

Reaction with Phenyl Isocyanate.—A mixture of 11.58 g (0.03 mol) of 2 (R, R' = C₆H₅) and 10.71 g (0.09 mol) of phenyl isocyanate is heated at 150° for 7 hr. After cooling the residue is trituated with diethyl ether, and the precipitated solid is recrystallized from ethanol to afford 11 g (63.3%) of 4 (R, R', R'' = C₆H₅), mp 225–228°. Evaporation of the ethanol and recrystallization of the residue from benzene affords 3.7 g (75.3%) of N,N-dimethyl-N'-phenylurea, mp 129–130° (lit.¹⁹ mp 128°).

Reaction with *p*-Tolyl Isocyanate.—A mixture of 3.86 g (0.01 mol) of 2 (R, R' = C₆H₅) and 3.99 g (0.03 mol) of *p*-tolyl isocyanate is heated at 150° for 3 hr. After cooling the residue is trituated with diethyl ether, and the precipitated crude reaction product is repeatedly crystallized from ethanol to afford 1.3 g (22%) of 1,3-di-*p*-tolyl-6,8,10-triphenyl-1,3,6,8,10-pentaaza-spiro[4.5]decane-2,4,7,9-tetraone (4, R, R' = C₆H₅; R'' = 4-CH₃C₆H₄): mp 188–190°; ir (CHCl₃) 1786, 1721, 1675 cm⁻¹ (C=O).

Anal. Calcd for C₃₇H₂₉N₅O₄: C, 73.14; H, 4.81; N, 11.52. Found: C, 72.96; H, 4.72; N, 11.88.

Registry No.—2 (R = C₆H₅), 17350-48-0; 4 (R, R' = C₆H₅; R'' = 4-CH₃C₆H₄), 17393-30-5; N,N-dimethylformamide, 68-12-2.

(18) F. B. Dains, *Ber.*, **35**, 2498 (1902).

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