

The Chemistry of Sulfonyl Isocyanates. V. Reactions with Aromatic Compounds¹

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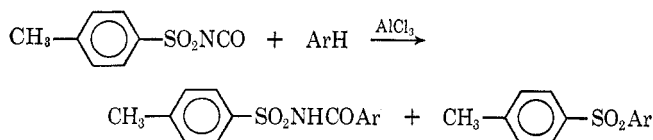
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p-Toluenesulfonyl isocyanate (I) reacted with benzene, anisole, toluene, chlorobenzene, naphthalene, and anthracene to give *N*-(*p*-toluenesulfonyl)amides. Similarly, *p*-chlorobenzenesulfonyl isocyanate (XI) reacted with benzene, anisole, toluene, chlorobenzene, and naphthalene to give the corresponding *N*-(*p*-chlorobenzenesulfonyl)amides. The optimum conditions for obtaining 1:1 addition products were at room temperature, with AlCl₃ as catalyst, and with a ratio of AlCl₃ to isocyanate of 2.5. At higher temperatures sulfones were produced along with amides.

The reactions of sulfonyl isocyanates with hindered alcohols and phenols,² triarylmethanols,^{3,4} and Grignard reagents⁵ have been extensively studied in this laboratory.

It was shown by Billeter that, when benzenesulfonyl isocyanate was mixed with benzene in the presence of AlCl₃, *N*-(benzenesulfonyl)benzamide was obtained.⁶ In more recent years Effenberger and Gleiter have studied the reactions of isocyanates with aromatic nuclei using Friedel-Crafts-type catalysts.⁷ In general the isocyanates served as acylating agents and gave amides. The above workers studied the reactions of benzene, fluorobenzene, and *m*-dichlorobenzene with *p*-toluenesulfonyl isocyanate (I) at 80–90°. The products consisted of both amide and sulfone.



This paper records the results that we have obtained from the reactions of sulfonyl isocyanates with a wide variety of aromatic compounds and under varying conditions of reactant ratios, catalysts, and temperatures. A summary of the results is given in Tables I and II.

The experimental evidence shows that optimum conditions for obtaining 1:1 addition product from *p*-toluenesulfonyl isocyanate (I) and benzene are with *ca.* 2.5 mol of AlCl₃ per 1 mol of I and with a large excess of benzene at room temperature. Apparently, at 0° the reaction does not go to completion and at 80° decomposition occurs. The same generalizations may be made for the reactions with anisole and toluene, although the sensitivity to isocyanate/AlCl₃ ratio was not quite so great as with benzene. Consistent with the findings of Effenberger and Gleiter,⁷ a large excess of I and AlCl₃ with respect to benzene gave phenyl *p*-tolyl sulfone (IV).

Chlorobenzene gave poor yields of product with both I and *p*-chlorobenzenesulfonyl isocyanate (XI). At high temperature there was a great tendency for

TABLE I
REACTIONS WITH *p*-TOLUENESULFONYL ISOCYANATE

ArH	Isocyanate/ AlCl ₃ ratio	Temp, °C	Yield, %	
C ₆ H ₆	1:1	Room	28.5 + oil	
	1:2	Room	53.3	
	1:3	Room	89.9	
	1:4	Room	79.9	
	1:2.5	0	50.7	
	1:2.5	Room	91.3	
	1:2.5	80	67.9	
	C ₆ H ₅ OCH ₃	1:1.1	Room	58.3
		1:1.1	80	Trace + oil
		1:2	Room	66.8
1:2.5		0	63.3	
1:2.5		Room	74.1	
1:2.5		80	59.1	
C ₆ H ₅ CH ₃	1:2.5	0	62.0	
	1:2.5	Room	67.4	
	1:2.5	80	45.2	
	1:2.5	Room	16.6 +	
C ₆ H ₅ Cl	1:2.5	0	<i>p</i> -toluenesulfonamide	
	1:2.5	80	Sulfonamide + oils	
	1:2.5	80	8.1 + 51.5% <i>p</i> -C ₇ H ₇ SO ₂ C ₆ H ₄ Cl- <i>p</i> (VIII)	
C ₁₀ H ₈	1:2	Room	69.1	
C ₁₄ H ₁₀	1:1	Room	49.2	

TABLE II
REACTIONS WITH *p*-CHLOROBENZENESULFONYL ISOCYANATE

ArH	Isocyanate/ AlCl ₃ ratio	Temp	Yield, %
C ₆ H ₆	1:2.5	Room	62.6
C ₆ H ₅ OCH ₃	1:2.5	Room	55.1
C ₆ H ₅ CH ₃	1:2.5	Room	79.4
C ₆ H ₅ Cl	1:2.5	Room	11.7 + oils
C ₆ H ₅ Cl	1:2.5	Reflux	19.3 + 31.4% sulfone (XVII)
C ₁₀ H ₈	1:2.5	Room	72.8

sulfone formation. The naphthalene and anthracene reactions were carried out in CS₂ solution and gave good yields of products.

Other catalysts, including SnCl₄, FeCl₃, BF₃·O(C₂H₅)₂, and ZnCl₂, were used instead of AlCl₃. In no case were the results satisfactory. Only *p*-toluenesulfonamide (II) and *p*-chlorobenzenesulfonamide (XIII), along with oils, were obtained.

(1) Taken in part from the M.S. thesis of L. C. Y., DePauw University, 1968.

(2) J. W. McFarland and J. B. Howard, *J. Org. Chem.*, **30**, 957 (1965).

(3) J. W. McFarland, D. E. Lenz, and D. J. Grosse, *ibid.*, **31**, 3798 (1966).

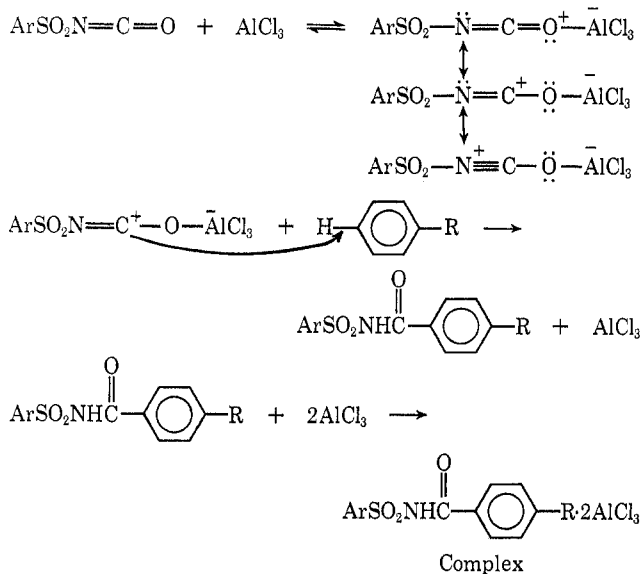
(4) J. W. McFarland, D. E. Lenz, and D. J. Grosse, *ibid.*, **33**, 3514 (1968).

(5) J. W. McFarland and W. A. Burkhardt, III, *ibid.*, **31**, 1903 (1966).

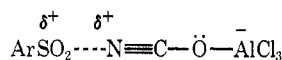
(6) O. C. Billeter, *Ber.*, **37**, 690 (1904).

(7) F. Effenberger and R. Gleiter, *ibid.*, **97**, 472 (1964).

The mechanism below for the acylation of aromatic nuclei with isocyanates is consistent with experimental facts.



The fact that sulfones are often formed at higher temperatures indicates that a species such as the following may be a resonance form of the isocyanate-AlCl₃ complex.



Somewhat analogously, arylsulfonyl halides are known to form sulfones with aromatic hydrocarbons in the presence of AlCl₃.

Experimental Section

p-Toluenesulfonyl isocyanate (I) and *p*-chlorobenzenesulfonyl isocyanate (XI) were obtained from the Upjohn Co., Carwin Organic Chemicals, and used without further purification. Benzene and toluene were dried over sodium before use. Anisole and chlorobenzene were dried over anhydrous calcium chloride, and anthracene and naphthalene were dried under vacuum.

Reactions of *p*-Toluenesulfonyl Isocyanate (I). **A. With Benzene.**—To a stirred slurry of 3.39 g (0.025 mol) of AlCl₃ and 70 ml of dry benzene in a 250-ml three-necked round-bottomed flask was added a solution of 2.00 g (0.0102 mol) of I in 30 ml of dry benzene during 20 min under nitrogen. The yellow-brown solution was stirred at room temperature (RT) for another 3.5 hr and then hydrolyzed with 100 g of ice and 25 ml of concentrated HCl, and 100 ml of ether was added.

The aqueous layer was washed with two 25-ml portions of ether and the combined organic extracts were washed with four 25-ml portions of water and dried over MgSO₄. Removal of solvent under reduced pressure gave 2.75 g (96.6%) of white solid, mp 128–140°. Recrystallization from benzene-petroleum ether afforded 2.56 g (91.3%) of *N*-(*p*-toluenesulfonyl)benzamide (III), mp 144–146° (lit.⁸ mp 147°).

The other reactions of I and benzene were discussed in the preceding section.

B. With Anisole.—A solution of 2.86 g (0.0145 mol) of I in 30 ml of anisole was added dropwise with stirring under N₂ to a mixture of 4.90 g (0.0366 mol) of AlCl₃ and 20 ml of anisole during 20 min at RT. The mixture was stirred for another 3.5 hr and hydrolyzed as above. After the addition of 50 ml of ether, the layers were separated and the aqueous phase was washed with two 25-ml portions of ether. The combined organic extracts were washed with four 25-ml portions of water, dried over anhydrous MgSO₄, and concentrated under reduced pressure. White solid weighing 3.99 g (89.5%) was obtained, mp 161–178°.

(8) A. Kemp and H. Stephen, *J. Chem. Soc.*, 110 (1948).

Recrystallization from benzene-petroleum ether gave 3.30 g (74.1%) of *N*-(*p*-toluenesulfonyl)-*p*-anisamide (V): mp 176–177° (lit.⁹ mp 176°); ir 3250 (NH) and 1705 cm⁻¹ (C=O).

C. With Toluene.—To 5.48 g (0.0411 mol) of AlCl₃ in 30 ml of dry toluene was added 3.24 g (0.0164 mol) of I in 20 ml of dry toluene under N₂ during 20 min. Work-up as above afforded 4.08 g (82.2%) of solid, mp 111–132°. Recrystallization from benzene-petroleum ether gave 3.19 g (67.4%) of *N*-(*p*-toluenesulfonyl)-*p*-toluamide (VI): mp 137–138° (lit. mp 138–139°); ir 3300 and 1700 cm⁻¹.

D. With Chlorobenzene.—The reaction was carried out as above, with 3.10 g (0.0157 mol) of I, 5.24 g (0.039 mol) of AlCl₃, and 50 ml of chlorobenzene. After addition, the solution was stirred for an additional 3.5 hr at RT. After work-up an oil (3.65 g) was obtained, which partially solidified upon standing for 3 days. Shaking with benzene gave 0.45 g (17.0%) of insoluble solid: mp 135–137.5°; mmp 135–138° with *p*-toluenesulfonamide (II).

When petroleum ether was added to the filtrate, 1.87 g of oily solid separated which showed ir absorption at 3300 and 1700 cm⁻¹. Recrystallization from benzene-petroleum ether yielded 0.77 g (16.6%) of *N*-(*p*-toluenesulfonyl)-*p*-chlorobenzamide (VII), mp 192–194° (lit.¹⁰ mp 195°).

Other reactions with chlorobenzene in which temperatures and reactant ratios were varied are shown in the discussion.

E. With Naphthalene.—A solution of 2.81 g (0.0146 mol) of I in 20 ml of CS₂ was added dropwise to a mixture of 2.80 g (0.0285 mol) of AlCl₃ and 1.95 g (0.0153 mol) of naphthalene in 60 ml of CS₂ under N₂ during 20 min. The reaction mixture was stirred for an additional 3.5 hr and then hydrolyzed. During hydrolysis, 1.96 g of pink solid separated, mp 141–147°. Work-up of the organic layer gave another 1.88 g (total 3.84 g, 82.5%) of solid, mp 143–147°. Recrystallization of the combined solids from benzene gave 2.64 g of *N*-(*p*-toluenesulfonyl)- α -naphthamide (IX), mp 146–148° (lit.¹¹ mp 150°).

F. With Anthracene.—To a mixture of 2.35 g (0.0131 mol) of AlCl₃ and 2.23 g (0.0125 mol) of anthracene in 70 ml of CS₂ was added 2.35 g (0.0119 mol) of I during 20 min under N₂. The mixture was stirred for an additional 3.5 hr at RT and hydrolyzed to give 2.18 g (49.2%) of yellow solid, mp 199–224°. Recrystallization from ethanol gave *N*-(*p*-toluenesulfonyl)-9-anthramide (X): mp 225.5–227.5°; ir 3250 (s, NH) and 1700 cm⁻¹ (s, C=O).

Anal. Calcd for C₂₂H₁₇NO₃S: C, 70.5; H, 4.53; N, 3.73; S, 8.53. Found: C, 70.45; H, 5.34; N, 3.91; S, 8.95.

Reactions of *p*-Chlorobenzenesulfonyl Isocyanate (XI). **A.**

With Benzene.—A solution of 2.82 g (0.013 mol) of XI in 20 ml of dry benzene was added dropwise under N₂ to a stirred slurry of 0.0325 mol of AlCl₃ in 50 ml of dry benzene at RT during 20 min. The mixture was stirred at RT for 3.5 hr and worked up, and the solvent was removed under vacuum to give 3.21 g (83.3%) of white solid, mp 172–181°. Recrystallization from ethanol gave *N*-(*p*-chlorobenzenesulfonyl)benzamide (XII): mp 183.5–185° (lit.¹² mp 184–185.5°); ir 3200 and 1700 cm⁻¹.

B. With Anisole.—An experiment similar to the one above using 3.10 g (0.0143 mol) of XI, 50 ml of anisole, and 4.76 g (0.0357 mol) of AlCl₃ afforded 4.12 g (88.8%) of solid, mp 165–173°. Recrystallization from benzene yielded 3.67 g (79.1%) of *N*-(*p*-chlorobenzenesulfonyl)-*p*-anisamide (XIV), mp 179–181°.

Anal. Calcd for C₁₄H₁₂ClNO₂S: C, 51.69; H, 3.69; Cl, 10.79; N, 4.30; S, 9.84. Found: C, 52.06; H, 3.80; Cl, 10.71; N, 4.47; S, 9.90.

C. With Toluene.—When 2.60 g (0.012 mol) of XI in 20 ml of toluene was added to 0.03 mol of AlCl₃ in 30 ml of toluene in a reaction similar to that with benzene, 2.53 g (68.0%) of solid, mp 140–157°, was obtained. Recrystallization from ethanol gave 2.05 g of *N*-(*p*-chlorobenzenesulfonyl)-*p*-toluamide (XV): mp 166–168°; ir 3200 (s) and 1700 cm⁻¹ (s).

Anal. Calcd for C₁₄H₁₂ClNO₂S: C, 54.36; H, 3.88; Cl, 11.32; N, 4.53; S, 10.35. Found: C, 55.13; H, 4.11; Cl, 11.55; N, 4.81; S, 10.51.

D. With Chlorobenzene.—From 2.60 g (0.012 mol) of XI, 50 ml of chlorobenzene, and 4.04 g (0.03 mol) of AlCl₃ at RT

(9) Swiss Patent 255,615 (1949); *Chem. Abstr.*, **43**, 7963b (1949).

(10) J. R. Geig, British Patent 598,536 (1948); *Chem. Abstr.*, **42**, 6379g (1948).

(11) Swiss Patent 255,625 (1949); *Chem. Abstr.*, **43**, 7963b (1949).

(12) N. V. Khromov-Borisov, *J. Appl. Chem. USSR* (Engl. Transl.), **18**, 612 (1945); *Chem. Abstr.*, **40**, 6365 (1946).

was obtained 3.18 g of oily solid. Slurring with benzene afforded 0.90 g (22.8%) of solid, mp 122–157°. Recrystallization from ethanol gave *N*-(*p*-chlorobenzenesulfonyl)-*p*-chlorobenzamide (XVI): constant mp 181–182°;¹³ ir 3250 and 1690 cm⁻¹.

Evaporation of the solvent produced an oil.

Another reaction with the same ratio of II and AlCl₃ was carried out as above, except that the mixture was heated under reflux for 3.5 hr. A solid, 3.55 g, mp 75–129°, was obtained, which, after slurring with benzene, gave 0.96 g (19.3%) of XVI: constant mp 179–181°; mmp 180–182° with XVI prepared at RT.

The filtrate was concentrated under reduced pressure and 1.36 g (31.4%) of solid was obtained. Recrystallization from ethanol gave a product with constant mp 147–149.5° which showed no NH or C=O absorption in the ir. The literature reported¹⁴ *p,p'*-dichlorodiphenyl sulfone (XVII) to melt at 147.5°.

(13) W. Hentrich and H. Engelbrecht, German Patent 765,524 (1952); *Chem. Abstr.*, **49**, 15967 (1955).

E. With Naphthalene.—A solution of 2.74 g (0.0126 mol) of XI in 20 ml of CS₂ was added dropwise at RT to 4.34 g (0.0316 mol) of AlCl₃ and 3.23 g (0.0253 mol) of naphthalene in 60 ml of CS₂ under N₂ during 20 min. After the mixture was stirred for an additional 3.5 hr at RT and hydrolyzed, 3.79 g of sticky solid was obtained. Recrystallization from benzene yielded 3.17 g (72.5%) of *N*-(*p*-chlorobenzenesulfonyl)- α -naphthamide (XVIII): mp 145–146.5°; ir 3300 and 1680 cm⁻¹.

Anal. Calcd for C₁₇H₁₂ClNO₂S: C, 59.13; H, 3.47; Cl, 10.14; N, 4.05; S, 9.26. Found: C, 59.27; H, 3.27; Cl, 10.35; N, 4.12; S, 9.06.

Registry No.—I, 4083-64-1; X, 22187-53-7; XI, 5769-15-3; XIV, 22187-55-9; XV, 22187-56-0; XVIII, 22187-57-1; benzene, 71-43-2; anisole, 100-66-3; toluene, 108-88-3; chlorobenzene, 108-90-7; naphthalene, 91-20-3; anthracene, 120-12-7.

(14) J. Huismann, German Patent 701,954 (1941); *Chem. Abstr.*, **36**, 98 (1942).

Photochemical Cyclizations. I. Preparation of Benzo[f]quinolines by Photolysis of 2-Stilbazole Derivatives¹

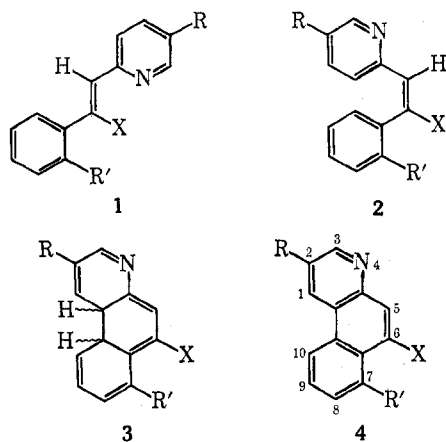
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The photochemical behavior of a series of 2-stilbazole derivatives 1a–1f has been investigated. In general, these compounds undergo oxidative photocyclization to benzo[f]quinolines 4. The effect of various experimental parameters (wavelength of light, solvent, and additives) on the photocyclization reaction is reported and discussed. In two cases, additional photoproducts have been isolated and characterized.

The photochemical behavior of a series of 2-stilbazole derivatives 1a–1f was investigated as part of a program



- a, X = H; R, R' = H
 b, X = CN; R, R' = H
 c, X = CN; R = OCH₃; R' = H
 d, X = COOCH₃; R, R' = H
 e, X = H; R = H; R' = NHCOCH₃
 f, X = H; R = H; R' = NO₂

directed toward the synthesis of various ergot and clavine alkaloids.

Irradiation of these compounds could be expected to

(1) Abstracted in part from the dissertation submitted by P. L. Kumler to the Graduate School of the University of Rochester in partial fulfillment of the requirements for the Ph.D. degree, May 1967.

(2) (a) National Institutes of Health Predoctoral Fellow, 1966–1967. To whom correspondence should be addressed: Department of Chemistry, University of Chicago, Chicago, Ill. 60637. (b) National Institutes of Health Predoctoral Fellow, 1968–present.

cause rapid *trans-cis*³ isomerization (1 \rightleftharpoons 2) and subsequent cyclization to the dihydrobenzo[f]quinolines 3, which should be readily oxidized to the benzo[f]quinolines 4. The photochemical cyclization of stilbene and its derivatives has received considerable attention,⁵ but the photochemistry of stilbazoles has not been as thoroughly investigated.⁶

The mechanism of the photocyclization reaction has not been completely elucidated, but is generally believed to involve formation of dihydrophenanthrene derivatives analogous to 3^{7,8} and subsequent oxidation of these species. The multiplicity of the excited state responsible for photocyclization has not been clarified but is generally believed to be the singlet state.⁸ Recent Hückel molecular orbital calculations for cyclization of monosubstituted stilbenes suggest, however, that cyclization proceeds from a vibrationally

(3) We have chosen to describe the configuration about the double bond of these compounds as being derivatives of *cis*- and *trans*-2-stilbazole. If the configuration of these compounds is specified by use of the descriptors *E* and *Z*,⁴ compounds 1a, 1e, and 1f are of the *E* configuration and compounds 1b–1d are of the *Z* configuration; compounds 2 are described by the opposite descriptors.

(4) J. E. Blackwood, C. L. Gladys, K. L. Loenig, A. E. Petrarca, and J. E. Rush, *J. Amer. Chem. Soc.*, **90**, 509 (1968); J. E. Blackwood, C. L. Gladys, A. E. Petrarca, W. H. Powell, and J. E. Rush, *J. Chem. Soc.*, **8**, 30 (1968).

(5) F. R. Stermitz in "Organic Photochemistry," Vol. 1, O. L. Chapman, Ed., Marcel Dekker, Inc., New York, N. Y., 1967, pp 247–282.

(6) (a) C. E. Loader, M. V. Sargent, and C. J. Timmons, *Chem. Commun.*, 127 (1965); (b) C. E. Loader and C. J. Timmons, *J. Chem. Soc.*, **C**, 1457 (1967); (c) C. E. Loader and C. J. Timmons, *ibid.*, 1078 (1966); (d) C. E. Loader and C. J. Timmons, *ibid.*, 1343 (1967); (e) C. E. Loader and C. J. Timmons, *ibid.*, 330 (1968); (f) P. Bortolus, G. Cauzzo, and G. Gallazzo, *Tetrahedron Lett.*, 239 (1966).

(7) W. M. Moore, D. D. Morgan, and F. R. Stermitz, *J. Amer. Chem. Soc.*, **85**, 829 (1963).

(8) K. A. Muszkat and Ernst Fischer, *J. Chem. Soc.*, **B**, 662 (1967), and references cited therein.