(60%) (glpc retention times of 4.5–14 min) and one major component (40%) (time 22 min). Isolation by preparative glpc afforded the major component methyl (Δ^2-2,3-dipropylcyclopropenylcarbinyl) carbonate **6**. Two of the minor components were identified as Δ^2-2,3-dipropylcyclopropenylcarbinyl alcohol (**9**) and *cis*- and *trans*-2-propyl-3-methyl-2-hexenal (**5**) as described above. Elution with ether then afforded 200 mg (15%) of 3,4-dipropylpyridazine (**8**).

B.—A 5-min-old slurry of 200 mg (3.7 mmol) of sodium methoxide, 425 mg (1.7 mmol) of **2**, and 1 drop of methanol in 30 ml of ether was quenched by the addition of 4 ml of glacial acetic acid, resulting in vigorous gas evolution. The mixture was poured into 50 ml of water and the layers were separated. The ether layer was washed with water, 10% aqueous $NaHCO_3$, and saturated aqueous NaCl. After drying ($MgSO_4$), the solution was concentrated *in vacuo* to an oil (300 mg). Nmr showed no absorption at 3.95 ppm. Molecular distillation of the oil at 100° (0.05 mm) left no residue. Glpc (160°) showed a group of seven peaks with retention times of 4 to 14 min (38%), and two major peaks with retention times of 15.5 (38%) and 22 min (24%) (percentage by disk integration of peak areas). The peak with retention time of 22 min corresponded to the methyl carbonate **6**; none of the pyridazine **8** (retention time 36.5 min) could be detected. The peak with a retention time of 15.5 min was collected by preparative glpc and identified as Δ^2-2,3-dipropylcyclopropenylcarbinyl acetate (**12**) by spectral comparison with an authentic sample.

By comparison, a mixture of 1.14 g (4.8 mmol) of **2** and 0.59 g (11 mmol) of $NaOCH_3$ when decomposed as in part A afforded only 0.4 g of oil when subjected to molecular distillation at 100° (0.05 mm), leaving *ca.* 100 mg of nonvolatile residue which showed an infrared band at 1640 cm^{-1}. Glpc of the oil (160°) showed the group of seven peaks with retention times of 4 to 14 min (33%), and peaks with retention times of 22 (27%) and 36.5 min (20%). The latter two corresponded to the previously identified methyl carbonate **6** and pyridazine **8**. (Glpc percentages total 80%; the remaining 20% of the reaction mixture is the nonvolatile material removed by distillation.)

C.—A 5-min-old slurry of 270 mg (5 mmol) of sodium methoxide, 600 mg (2.5 mmol) of **2**, and 1 drop of methanol in 10 ml of ether was filtered in an inert atmosphere. An aliquot of the pink filtrate was transferred *via* syringe to an infrared cell. The infrared spectrum showed a strong diazo band at 2040 cm^{-1}.

Reaction of 6 with Sodium Methoxide.—A solution of 200 mg of **6** in 10 ml of ether was treated with 600 mg of sodium methoxide. After the solution was stirred for 3.5 hr at room temperature, 10 ml of water was added and the layers were separated. The ether layer was washed with saturated aqueous NaCl and dried ($MgSO_4$). Glpc (160°) showed a mixture of 15% of Δ^2-2,3-dipropylcyclopropenylcarbinyl alcohol and 85% of **6**.

Lead Tetraacetate Oxidation of 3.—A solution of 2.7 g (15 mmol) of **3** in 40 ml of methylene chloride was added over 1.5 hr to an ice-cold solution of 9.8 g (22 mmol) of lead tetraacetate in 80 ml of methylene chloride. Nitrogen evolution was evident during the addition and a white precipitate of lead acetate formed. After the addition was complete, the mixture was allowed to warm to room temperature for 0.5 hr. The mixture was poured into 30 ml of water and the layers were separated. The organic phase was washed with 10% aqueous $NaHCO_3$, dried ($MgSO_4$), and concentrated *in vacuo* to an oil (3.3 g). The oil (2 g) was chromatographed on 30 g of silica gel. Elution with hexane (100 ml) afforded 0.197 g of an unidentified unsaturated acetate, ir 3040 (m), 1740 (s), 1630 cm^{-1} (w), no cyclopropene C=C. Elution with 25% ether in hexane afforded 1.0 g (51%) of methyl (Δ^2-2,3-dipropylcyclopropenyl)carbinyl acetate (**15**), identical with an authentic sample.

Mercuric Oxide Oxidation of 3.—A solution of 2.3 g (13 mmol) of **3** in 20 ml of petroleum ether (bp 30–60°) was added over 10 min to a suspension of 6.1 g (26 mmol) of mercuric oxide (yellow powder) in 200 ml of petroleum ether. The mixture was stirred at high speed in a 500-ml Morton flask at room temperature for 24 hr.

The mixture was filtered through a bed of $MgSO_4$ and the filtrate was concentrated *in vacuo* to a brown oil (2.2 g). The oil was chromatographed on 50 g of silica gel. Elution with 600 ml of 1:3 ether–hexane afforded a dark multicomponent oil which was not investigated further. Elution with 450 ml of 3:1 ether–hexane afforded 1.35 g (58%) of a single-component oil by glpc, identified as 3,4-dipropyl-6-methylpyridazine (**17**): ir 3030 (w), 1590 (s), 1540 cm^{-1} (w); nmr ($CDCl_3$) δ 1.00 (6 H, t), 1.78 (4 H, m), 2.58 (2 H, t), 2.62 (3 H, s), 2.95 (2 H, t), 7.10 (1 H, s); uv $\lambda_{max}^{pet\ ether}$ 262 mμ (log ϵ 3.3), 334 (2.5); mass spectrum *m/e* 178, 163, 150, 135. An analytical sample was obtained by preparative glpc as a colorless oil.

Anal. Calcd for $C_{11}H_{18}N_2$: C, 74.11; H, 10.18. Found: C, 74.30; H, 10.26.

Thermal Stability of 3.—A solution of **3** (0.7 g) in 50 ml of absolute ethanol was refluxed for 18 hr. The ethanol was removed *in vacuo* at room temperature. The nmr and ir spectra of the residue were identical with those from freshly prepared **3**.

A solution of **3** (150 mg) in 0.5 ml of $CDCl_3$ was placed in a sealed nmr tube. The nmr spectrum showed an 18:2 integral ratio of CH (δ 0.95–2.42) to NH protons (δ 4.50). After 24 hr at room temperature the ratio was 18:1.3, consistent with gradual azine formation. No changes were observed in the CH portion of the spectrum.

Registry No.—**2**, 35890-03-0; **6**, 35890-04-1; **7**, 35890-05-2; **8**, 35890-06-3; **9**, 35890-07-4; **13**, 35890-08-5; **15**, 35890-09-6; **17**, 35890-10-9; 1-cyano-2,3-dipropylcycloprop-2-ene, 7525-49-7; Δ^2-2,3-dipropylcyclopropenylcarbinylamine, 35890-12-1; Δ^2-2,3-dipropylcyclopropenylcarbinylamine hydrochloride, 35890-13-2; methyl *N*-(Δ^2-2,3-dipropylcyclopropenylcarbinyl)urethane, 7572-55-6.

Acknowledgment.—Acknowledgment is made to the Research Corporation for partial support of this work.

Photolysis of Phenyl- and Diphenyldiazomethanes in Alkyl and Allylic Sulfides

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Received April 14, 1972

Photolysis of phenyl- and diphenyldiazomethanes in dimethyl sulfide gives ortho-substituted sulfur compounds through the sulfonium ylide intermediate. Photodecomposition of phenyldiazomethane in benzyl methyl sulfide gives the insertion product of phenylcarbene into benzyl hydrogen, presumably by ylide rearrangement of the benzyl group. The reaction in allylic sulfides gave allyl(alkylthio)arylmethanes together with some cyclopropane derivatives. Thermal decomposition of phenyldiazomethane gives only addition product, but diphenyldiazomethane gives both addition and insertion products.

Dialkyl sulfides give stable sulfur ylides by addition of singlet carbenes containing strongly electron-withdrawing substituents. Bis(phenylsulfonyl)carbene could be trapped with di-*n*-butyl sulfide to give the ylide.[1] The photoinduced reaction of diazo biscar-

(1) J. Diekmann, *J. Org. Chem.*, **28**, 2933 (1963); **30**, 2272 (1965).

bonyl compounds with dimethyl sulfide also produced stable sulfur ylides.[2-4]

$$N_2C(COR)_2 + CH_3SCH_3 \xrightarrow{h\nu} (CH_3)_2\overset{+}{S}\overset{-}{C}(COR)_2$$
$$R = OCH_3, OC_2H_5, CH_3$$

However, in the reaction with allylic sulfides, the sulfonium ylide was not isolated and insertion of the carbene into the C–S bond was found to be important. The rationalization is the familiar one in which the insertion of electrophilic singlet carbene takes place in two steps: the formation of sulfonium ylide followed by the 2,3-sigmatropic rearrangement.[5-7]

$$:C(COR)_2 + CH_2{=}CHCH_2SR \longrightarrow CH_2{=}CHCH_2\overset{+}{S}R \longrightarrow$$
$$\overset{-}{C}(COR)_2$$

intermediate sulfur ylide

$$CH_2{=}CHCH_2C(COR)_2$$
$$SR$$

These approaches have been applied successfully on occasion in carbonylcarbene reactions, but little is known about the behavior of arylcarbenes in sulfur compounds. In this paper, we report the electrophilic reactions of phenyl- and diphenylcarbenes on sulfur compounds and the results are compared with those of sulfonium salts.

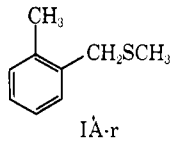
Results

Photochemical decomposition of phenyl- and diphenyldiazomethanes in a 20-mol excess of alkyl sulfide was carried out in Pyrex vessels, without degassing, using a Rikosha 400-W high-pressure mercury lamp. Photolysis was generally complete, as indicated by disappearance of the diazo band at 2040 cm^{-1} in the infrared spectrum. Products were identified by glpc retention time, ir, nmr, and elemental analysis.

Reactions of Phenyldiazomethane in Aliphatic Sulfides and Disulfides.—The photolysis of phenyldiazomethane in dimethyl sulfide was performed at room temperature. The sulfur ylide might be expected to form by electrophilic attack of singlet phenylcarbene on the sulfur atom. No more than a trace of sulfonium ylide could be observed from the analysis of the nmr spectrum of the reaction mixture. Product analysis by glpc showed the presence of *o*-methylbenzylmethyl sulfide (IA-r) in 20% yield; the structure was established by comparison with an authentic sample.[8] Stilbene and benzalazine were observed in 6 and 10% yields, respectively.

On the other hand, the reaction in diethyl and benzyl methyl sulfides gave the insertion products of phenylcarbene into the α-C–H bond. Reactions in diiso-

$$PhCHN_2 + CH_3SCH_3 \xrightarrow{h\nu}$$
I



IA-r

propyl and di-*tert*-butyl sulfides gave the olefin elimination products as major product.

$$PhCHN_2 + RSR^1 \xrightarrow{h\nu} RSCHR' + RSCH_2Ph$$
$$CH_2Ph$$

α-C–H insertion (A-In) elimination (E)

II, R = R^1 = C_2H_5 — VII, R = CH_3; R^1 = $PhCH_2$
III, R = R^1 = *i*-C_3H_7 — VIII, R = C_2H_5; R^1 = $PhCH_2$
IV, R = R^1 = *t*-C_4H_9 — IX, R = CH_3; R^1 = SCH_3
V, R = C_2H_5; R^1 = *t*-C_4H_9 — X, R = C_2H_5; R^1 = SC_2H_5
VI, R = Ph; R^1 = C_2H_5

In these reactions, benzaldehyde, benzalazine, and *cis*- and *trans*-stilbene were also obtained as major products (total yields of these products were approximately 30%).

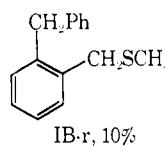
The photolysis of phenyldiazomethane in dimethyl and diethyl disulfide gave as the principal products methyl benzyl sulfide (IA-E) in 15% yield and ethyl benzyl sulfide (IIA-E) in 17% yield, respectively (Table I).

TABLE I
YIELDS OF PRODUCTS FROM THE PHOTOLYSIS OF PHENYLDIAZOMETHANE IN ALIPHATIC SULFIDES AND DISULFIDES

Sulfide	Elimination (= A-E), %	Insertion (= A-In), %
II	4	35
III	29	0
IV	25	0
V	21 (IIA-E)	0
VI	19	Trace
VII	0	20
VIII	3	22
IX	15 (IA-E)	0
X	17 (IIA-E)	0

Photolysis of Diphenyldiazomethane in Aliphatic Sulfides and Disulfides.—The photolysis of diphenyldiazomethane in alkyl sulfides and disulfides was carried out in Pyrex vessels without degassing. The crude reaction mixture in dimethyl sulfide showed an nmr signal at 2.10 ppm (singlet) in chloroform, which might be assigned to the proton signal of $CH_3SCH_3^+$, but the corresponding sulfonium ylide could not be isolated by thin layer chromatography. Glpc analysis showed the formation of *o*-benzylbenzylmethyl sulfide (IB-r) and 1,1-diphenyl-2-methylthioethane (IB-In) in 10 and 40% yields, respectively. The structures of these products were determined by elemental and spectral analyses. Diphenylazine and benzophenone (about 10% each) were minor products.

$$Ph_2CN_2 + CH_3SCH_3 \xrightarrow{h\nu}$$



IB-r, 10%

$$+ Ph_2CHCH_2SCH_3$$
IB-In, 40%

An analogous α-C–H insertion product (IIB-In) was also observed together with some elimination product (IIB-E) when the photolysis of dihenyldiazomethane

(2) W. Ando, T. Yagihara, S. Tozune, and T. Migita, *J. Amer. Chem. Soc.*, **91**, 2786 (1969).
(3) W. Ando, T. Yagihara, S. Tozune, S. Nakaido, and T. Migita, *Tetrahedron Lett.*, 1979 (1969).
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(5) W. Ando, K. Nakayama, K. Ichibori, and T. Migita, *J. Amer. Chem. Soc.*, **91**, 5164 (1969).
(6) W. Ando, S. Kondo, and T. Migita, *ibid.*, **91**, 6516 (1969).
(7) W. Ando, S. Kondo, K. Nakayama, K. Ichibori, K. Kohda, H. Yamato, I. Imai, S. Nakaido, and T. Migita, *ibid.*, **94**, 3870 (1972).
(8) M. Yoshimine and M. J. Hatch, *ibid.*, **89**, 5831 (1967).

was carried out in diethyl sulfide. On the other hand, in diisopropyl sulfide, two major products, isopropylbenzhydryl sulfide (IIIB-E) and isopropyl(isopropylthio)diphenylmethane (IIIB-In), were obtained in 20 and 15% yields, respectively.

$$Ph_2CN_2 + C_2H_5SC_2H_5 \xrightarrow{h\nu} \underset{\text{IIB-E}}{C_2H_5SCHPh_2} + \underset{\text{IIB-In}}{C_2H_5SCHCH_3(CHPh_2)}$$

$$Ph_2CN_2 + (CH_3)_2CHSCH(CH_3)_2 \xrightarrow{h\nu} \underset{\text{IIIB-E}}{(CH_3)_2CHSCHPh_2} + \underset{\text{IIIB-In}}{(CH_3)_2CHSCPh_2CH(CH_3)_2}$$

Product IIIB-In was identified as the insertion product of diphenylcarbene into the C–S bond. Its nmr spectrum showed two isopropyl groups as a doublet at 0.82 and 0.87 ppm. This product was synthesized independently from the reaction of isopropyl diphenylcarbinol and isopropyl mercaptan.[9] Product IIIB-E was found to be the elimination product identical with that found in the reaction of diphenyldiazomethane with isopropyl mercaptan.

Similar elimination products were also found in the reactions of diphenyldiazomethane with dimethyl- and diethyl disulfide. Reaction in dimethyl disulfide gave methyl benzhydryl sulfide IB-E in 49% yield; in diethyl disulfide, ethyl benzhydryl sulfide IIB-E in 28% yield was formed together with 1,1-diphenylpropene (XI) in 21% yield.

$$Ph_2CN_2 + RSSR \xrightarrow{h\nu} \underset{R = CH_3, C_2H_5}{RSCHPh_2} + \underset{\text{XI}}{Ph_2C{=}CHCH_3}$$

Solvent Effects on the Reaction of Diphenyldiazomethane in Dimethyl Sulfide.—Photolyses of diphenyldiazomethane in dimethyl sulfide, diluted with an inert solvent such as benzene, cyclohexane, acetone, or mesityl oxide, were also done at room temperature without degassing. Use of purified cyclohexane or benzene (mole fraction 0.5) as diluent gave no change in the ratio of IB-r/IB-In, 0.3–0.4. This is to be compared with 0.25 in pure dimethyl sulfide. A control experiment showed that diluted solvents were not reacting with diphenyldiazomethane. A similar experiment was carried out using a mixture of dimethyl sulfide and acetone or mesityl oxide (mole fraction 0.5). Photolysis for 2.5 hr, followed by work-up and analysis by gas chromatography, gave the ratio of IB-r/IB-In of 3–3.5. It is clear that a major portion of the reaction product was apparently affected by solvent (Table II).

Reactions of Dialkylbenzhydrylsulfonium Salts.—Similar rearrangement and insertion products are observed with sulfonium salts. Dimethylbenzhydrylsulfonium bromide was prepared in low yield using diphenylbromomethane and dimethyl sulfide. The salt, though crystalline, was highly hygroscopic and the corresponding fluoroborate salt XII was therefore prepared. Sodium amide was added to a slurry of XII in acetone. However, IB-r was formed as major product together with trace of IB-In. In dimethyl sulfide, IB-r was also obtained as major product, but IB-In was formed in 5% yield. Alkylation of diethyl sulfide by diphenylbromomethane generated the crystalline sulfonium salt XIII; sodium amide converted the salt exclusively to rearrangement product XIIIB-r. However, none of IIB-In could be detected in acetone or benzene solvents. We attempted to prepare compound XIV using bromide, diisopropyl sulfide, and silver perchlorate. Addition of sodium amide to a benzene or acetone slurry of XIV afforded product IIIB-E and IIIB-In in comparable yields, as determined by vpc analysis. These results are compared with those obtained in the reaction of diphenyldiazomethane with alkyl sulfides.

(9) E. A. Fehnel and M. Carmack, *J. Amer. Chem. Soc.*, **71**, 84 (1949).

TABLE II

SOLVENT EFFECTS ON THE REACTION OF DIPHENYLDIAZOMETHANE WITH DIMETHYL SULFIDE

Solvent	Mole ratio (sulfide/solvent)	Product ratio (IB-r/IB-In)
Cyclohexane	3.3	0.2
	0.5	0.3
Benzene	0.3	0.3
	3.5	0.4
Acetone	0.3	3.2
	0.5	2.8
Mesityl oxide	0.3	3.5
	0.5	3.5

$$\underset{\text{XII}}{Ph_2CHS^+(CH_3)(CH_3)} \xrightarrow{NaNH_2} \text{IB-r} + \text{IB-In}$$

In acetone 55% 0%

In CH_3SCH_3 31% 5%

$$\underset{\text{XIII}}{Ph_2CHS^+(C_2H_5)_2} \xrightarrow{NaNH_2} \text{IIB-E} + \underset{\text{XIIIB-r}}{CH_2Ph\text{-}C_6H_4\text{-}CH(Me)SC_2H_5}$$

In acetone Trace 45%

In benzene 9% 64%

$$\underset{\text{XIV}}{Ph_2CHS^+(i\text{-}C_3H_7)(i\text{-}C_3H_7)} \xrightarrow[\text{benzene}]{NaNH_2} \text{IIIB-In} + \text{IIIB-E}$$

22% 23%

Reactions of Phenyl- and Diphenyldiazomethanes in Allylic Sulfides.—Thermal and photolytical decomposition of phenyl- and diphenyldiazomethanes produced insertion and addition products (Table III).

TABLE III

YIELDS OF PRODUCTS IN THE REACTION OF PHENYL- AND DIPHENYLDIAZOMETHANES IN ALLYLIC SULFIDES

		Sulfide			Insertion (i), %			Addition (a), %		
	R	R^1	R^2	R^3	*a*	*b*	*c*	*a*	*b*	*c*
XV	H	C_2H_5	H	H	0	49	31	29	0	4
XVI	H	C_2N_5	H	CH_3	0	45	30	0	0	0
XVII	H	*t*-Bu	H	H	0	54	29	28	0	6
XVIII	Ph	C_2H_5	H	H	26	38	26	20	3	0
XIX	Ph	C_2H_5	CH_3	H	15	43	21	7	0	0
XX	Ph	C_2H_5	H	CH_3	18	26	36	0	0	0
XXI	Ph	*t*-Bu	H	H	6	14	22	17	16	3

[a] Thermal decomposition at 110–140°. [b] Cupric sulfate catalyzed thermal decomposition at 110°. [c] Photolysis.

The photolysis of phenyldiazomethane in allyl sulfide afforded the principal product XV-i in 31% yield and the minor product XV-a in 4% yield. A control experiment demonstrated that these products were

not altered by reaction and work-up conditions. The product XV-i was found to be an insertion product of phenylcarbene into the allyl carbon–sulfur bond and XV-a to be an addition product of phenylcarbene to the C=C bond. The structures of these products were determined by elemental analysis and the examination of nmr and ir spectra. The reaction of phenyldiazomethane with γ-methylallyl ethyl sulfide gave XVI-i in 30% yield, which was identified as α-(1-methyl-2-propenyl)-α-ethylthiophenylmethane by spectral analyses. There was no trace of any isomer such as α-(2-butenyl)-α-ethylthiophenylmethane in the reaction products.[10] Insertion product XV-i was also

$$N_2CRPh + R^3CH{=}CR^2CH_2SR^1 \xrightarrow{h\nu} CH_2{=}CR^2CHR^3CRSR^1 + R^3CHCR^2CH_2SR^1$$

(Ph: insertion (i); CRPh: addition (a))

obtained in 49% yield when phenyldiazomethane was decomposed at 110° in the presence of cupric sulfate. No addition product was obtained. On the other hand, the thermolysis of phenyldiazomethane in allyl sulfide at 140° afforded XV-a in 29% yield, and C–S bond insertion product was not detected.

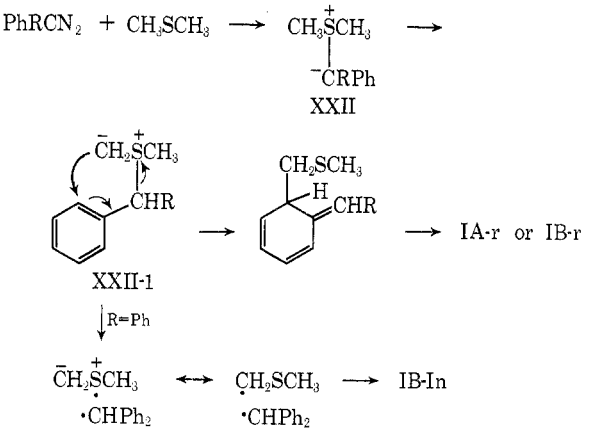
Similarly, in the thermolysis of diphenyldiazomethane without catalysis both addition and insertion products were obtained in comparable yields. On the other hand, the thermolysis and photolysis afforded the insertion product as major product.

Discussion

To date there is no concrete evidence that aryl-substituted sulfur ylides are formed in the reaction of aryldiazomethane with alkyl sulfides, although the photolysis of phenyl- and diphenyldiazomethane in benzyl methyl sulfide has been reported.[11] Relatively little is known about the isolation of stable onium ylide in the reaction of diazo compounds with heteroatoms.[1-3,12] The formation of onium ylides is explained as the electrophilic attack of singlet carbene on the nonbonding electron pair of the heteroatom.

In contrast to bis(carbomethoxy)carbene, which reacts with a number of alkyl sulfides to give stable ylides,[2,3] phenyl- and diphenylcarbene did not, but afforded the products which are considered to be produced by further reaction of the corresponding ylides.

It is possible that when phenyl- and diphenylcarbene react with sulfur atom to form the unstable sulfonium ylides, the Sommelet–Hauser and Stevens rearrangements products could be responsible for either sulfur ylides.[13] Thus, the formation of ortho-substituted products, IA-r and IB-r, involves presumably the rearrangement of an intermediate sulfonium ylide XXII in which less predominant ylide XXII-1 is the reactive intermediate and the benzene ring functions as an acceptor, similar to that proposed for the analogous rearrangement of sulfonium ion.[13] The Stevens 1,2-shift product, IB-In, probably arises from the intermediate XXII–1 with radical pair as suggested by other workers.[14-18] Analogous product was also obtained in the reaction of sulfonium salt, although the Sommelet–Hauser process predominates.



The insertion products of phenyl- and diphenylcarbene into α-C–H bond are the expected Stevens 1,2-shift products from the corresponding sulfonium ylides. Although the Stevens shifts have been reported in the reaction of dibenzylmethyl sulfonium salt[19] together with the Sommelet–Hauser product, none of Stevens product was obtained in the reaction of XIII. This is not in accord with the fact that phenyl- and diphenylcarbene gave only Stevens product and none of Sommelet–Hauser product in the reaction with diethyl sulfide. It is not clear that α-C–H insertion products are formed, whether by the direct insertion of the carbene into α-C–H or the formation of sulfonium ylide followed by the Stevens rearrangement through the radical pair. However, since the basicity of the intermediate carbanion on the sulfur ylide is one of the important factors controlling the Stevens or Sommelet–Hauser rearrangement, and the weak bases predominate Stevens product,[19] it could be possible that the sulfur ylide formed by the reaction of phenyl- and diphenylcarbene gives predominantly the Stevens 1,2-shift products, but not by sulfonium ion.

Photolysis of phenyldiazomethane in diisopropyl and di-*tert*-butyl sulfides gave only isopropyl and *tert*-butyl benzyl sulfides. In these reactions, the Sommelet–Hauser and Stevens products were not formed. The mechanism of these reactions is considered to be the formation of sulfonium ylide intermediate followed by cis elimination through five-membered cyclic transition states.

In the reaction with dialkyl disulfides, the elimination product seems reasonable to formulate as the formation of sulfonium ylide by electrophilic attack of the phenylcarbene on the sulfur atom followed by a cyclic concerted process. Similar cleavage of the sulfur–sulfur bond has been observed in the reaction of bis(carbo-

(10) A control experiment showed that the γ-methylallyl ethyl sulfide, did not isomerize to α-methylallyl ethyl sulfide, which was only detected in less than 1% amount either before or after photolysis.

(11) W. R. Bamford and T. S. Stevens, *J. Chem. Soc.*, 4675 (1952).

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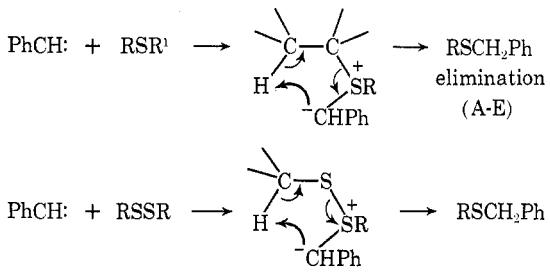
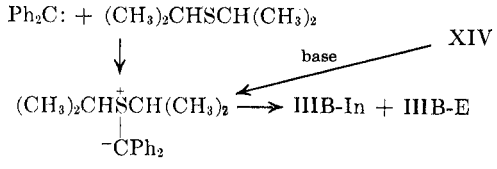


methoxy)carbene with alkyl disulfides as principal pathway.[20]

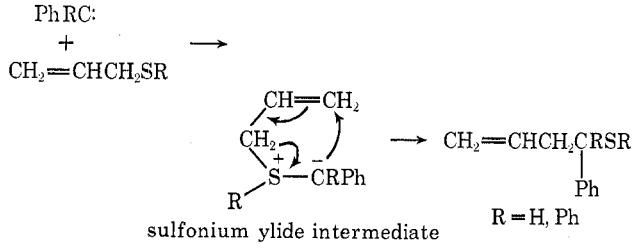
Photolysis of diphenyldiazomethane in diisopropyl sulfide also gave the elimination product together with the insertion product of diphenylcarbene into the C–S bond. The insertion of the carbene into the alkyl carbon–sulfur bond appears unusual and is considered to be analogous to that represented for the Stevens 1,2-shift of intermediate sulfonium ylide, in which the isopropyl group probably migrated from the sulfonium center to an adjacent carbanionic carbon. This mechanism is supported by the formation of analogous Stevens and the elimination products in the reaction of sulfonium salt XIV with sodium amide in benzene or acetone.



Accordingly, under the photolytic conditions, the phenyl and diphenylcarbenes could interact with sulfur atom to give either the Sommelet–Hauser, Stevens 1,2-shift, or β-elimination product, depending on the nature of the intermediate carbanion.

The formation of rearranged insertion products in the reactions of the carbene with allylic sulfides is also explained in terms of the ylide mechanism, as has been suggested in the similar reactions of carbonylcarbenes.[5-7]

The phenyl- and diphenylcarbenes or carbenoids generated in the photolysis or the copper sulfate thermal reaction convert the sulfide to sulfonium ylide followed by allylic 2,3-sigmatropic rearrangement, but do not convert the olefin to cyclopropane, showing little reactivity in comparison with sulfur atom.

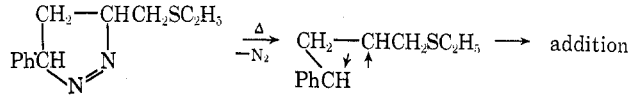


sulfonium ylide intermediate

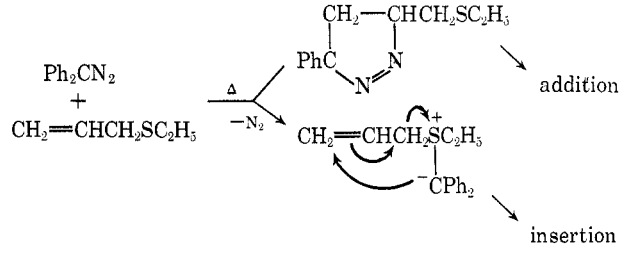
The thermal reaction of phenyl- and diphenyldiazomethanes (reaction conditions a) is also a reaction in which involvement of carbene is often assumed, and, as mentioned above, the sulfonium ylide intermediate was readily rationalized as resulting from attack of the carbene.

(20) W. Ando, T. Yagihara, S. Tozune, I. Imai, J. Suzuki, T. Toyama, S. Nakaido, and T. Migita, *J. Org. Chem.*, **37**, 1721 (1972).

However, the thermolysis of phenyldiazomethane in allyl sulfide at 140° afforded the product XV-a in 29% yield, and none of the C–S bond insertion product of the carbene was detected. It is now evident that the addition process is favored over the insertion process. Interpreting these reactions, the formation of addition product occurs not in carbene reactions, but in the addition of diazo compound itself on the C=C bond to form pyrazoline followed by loss of nitrogen and the formation of singlet diradical in which ring closure must occur. The phenylcarbene is not produced under the reaction conditions.



In the thermolysis of diphenyldiazomethane in allyl sulfide, both addition and insertion products were obtained in comparable yields, and in γ- or β-methylallyl sulfides, the insertion product was obtained as the only major product. These data indicate that the cyclopropane formation probably arises from the pyrazoline intermediate and the insertion product from the sulfonium ylide intermediate.



Under the reaction conditions, the diphenyldiazomethane could either decompose to produce the carbene or react with olefin to form the pyrazoline. The steric factor is most important for the pyrazoline formation giving the cyclopropane.

Experimental Section

Instruments.—Ir spectra were recorded on a Japan Spectroscopic Co. DS-21 spectrometer. Nmr spectra were recorded on a Varian A-60D spectrometer in CCl_4 solutions with an internal $(CH_3)_4Si$ standard. Gas–liquid partition chromatography (glpc) was used extensively for the separation and purification of products and for yield determinations. The internal standard method was used in yield determination. The glpc column used included 10% Carbowax 20M, 2 ft × 0.25 in. on Celite 22; 10% SF-96, 4 ft × 0.25 in. on Celite 545; and 5% SE-30, 4 ft × 0.25 in. on Celite 22.

Materials.—The reagents dimethyl, diethyl, and di-*tert*-butyl sulfides and dimethyl, diethyl, and diisopropyl disulfides were obtained commercially and purified by distillation before use. Benzyl methyl sulfide,[21] ethyl *tert*-butyl sulfide,[21] phenyl ethyl and phenyl isopropyl sulfides,[22] and allylic sulfides[23] were prepared by known procedure as referenced. Phenyldiazomethane was prepared by the action of sodium methoxide on benzaldehyde tosylhydrazine.[24] Diphenyldiazomethane was prepared by the oxidation of benzophenone hydrazone with yellow mercuric oxide.[25]

Synthesis of Benzhydryldimethylsulfonium Fluoroborate (XII).

(21) W. Windus and P. R. Shildneck, "Organic Syntheses," Collect. Vol. II, Wiley, New York, N. Y., 1943, p 345.
(22) A. Vogel, *J. Chem. Soc.*, 1822 (1948).
(23) D. S. Tarbell and W. F. Lovett, *J. Amer. Chem. Soc.*, **78**, 2259 (1956).
(24) R. A. Moss and U. H. Dolling, *ibid.*, **93**, 954 (1971).
(25) L. I. Smith and K. L. Howard, "Organic Syntheses," Collect. Vol. III, Wiley, New York, N. Y., 1955, p 351.

TABLE IV

NMR DATA FOR ARYLSULFUR COMPOUNDS[a]

IB-r: 1.90 (s, 3 H), 3.53 (s, 2 H), 4.11 (s, 2 H), 6.88–7.38 (m, 9 H). IB-In: 1.94 (s, 3 H), 3.08 (d, 2 H), 4.12 (t, 1 H), 6.85–7.40 (m, 10 H). IIA-In: 1.18 (d, 3 H), 1.23 (t, 3 H), 2.48 (q, 2 H), 2.89 (m, 3 H), 7.15 (s, 5 H). IIB-In: 1.15 (t, 3 H), 1.27 (d, 3 H), 2.30 (q, 2 H), 3.4–4.1 (m, 2 H), 6.9–7.4 (m, 10 H). IIIB-In: 0.82 (d, 6 H), 0.87 (d, 6 H), 1.97–2.42 (m, 1 H), 2.69–3.20 (m, 1 H), 7.06–7.52 (m, 10 H). IIIB-E: 1.24 (d, 6 H), 2.34–2.88 (m, 1 H), 5.13 (s, 1 H), 6.92–7.56 (m, 10 H). VIIA-In: 1.77 (s, 3 H), 3.06 (m, 2 H), 3.72 (m, 1 H), 7.09 (m, 10 H). XIIIB-r: 1.03 (t, 3 H), 1.33 (d, 3 H), 2.18 (q, 2 H), 4.06 (s, 2 H), 4.16 (m, 1 H), 6.9–7.6 (m, 9 H). XV-i: 1.11 (t, 3 H), 2.23 (q, 2 H), 2.55 (t, 2 H), 3.77 (t, 1 H), 4.95 (m, 2 H), 5.63 (m, 1 H), 7.22 (s, 5 H). XV-a: 0.8–1.2 (m, 2 H), 1.22 (t, 3 H), 1.5–2.0 (m, 1 H), 2.53 (d, + q, 4 H), 7.06 (m, 5 H). XVI-i: 0.96–1.13 (t + d, 6 H), 2.33 (m, 3 H), 3.62 (d, 1 H), 4.94 (m, 2 H), 5.62 (m, 1 H), 7.18 (s, 5 H). XVII-i: 1.14 (s, 9 H), 2.48 (t, 2 H), 3.79 (t, 1 H), 4.39 (m, 2 H), 5.55 (m, 1 H), 7.22 (s, 5 H). XVII-a: 1.29 (s, 6 H), 1.32 (m, 4 H), 2.57 (d, 2 H), 7.08 (m, 5 H). XVIII-i: 1.05 (t, 3 H), 2.10 (q, 2 H), 3.10 (d, 2 H), 4.7–5.6 (m, 3 H), 7.0–7.5 (m, 10 H). XVIII-a: 0.8–1.5 (m, 5 H), 1.19 (t, 3 H), 2.48 (q, 2 H), 6.8–7.5 (m, 10 H). XIX-i: 0.98 (t, 3 H), 1.33 (s, 3 H), 2.01 (q, 2 H), 3.07 (s, 2 H), 4.35 (m, 1 H), 4.75 (m, 1 H), 6.9–7.6 (m, 10 H). XIX-a: 1.0–1.5 (m, 5 H), 1.10 (t, 3 H), 1.25 (s, 2 H), 2.35 (q, 2 H), 6.8–7.6 (m, 10 H). XX-i: 1.00 (t, 3 H), 1.50 (d, 3 H), 1.95 (q, 2 H), 2.8–3.2 (m, 1 H), 4.70 (m, 2 H), 5.60 (m, 1 H), 7.0–7.5 (m, 10 H). XXI-i: 1.00 (s, 9 H), 3.20 (d, 2 H), 4.93 (m, 2 H), 5.60 (m, 1 H), 6.9–7.6 (m, 10 H). XXI-a: 1.16 (s, 9 H), 1.1–1.5 (m, 3 H), 2.23 (d, 2 H), 6.9–7.4 (m, 10 H).

[a] Satisfactory analytical data (±0.4% for C, H) were reported for all new compounds listed in the table. The nmr spectra are reported in δ units in parts per million downfield from internal TMS.

—To a 100-ml flask equipped with a stirrer were added 10 g (0.04 mol) of diphenylbromomethane and 5 g (0.08 mol) of dimethyl sulfide. The reaction mixture was stirred rapidly for 12 hr. The amorphous solid appeared. The organic layer was completely removed under vacuum. An aqueous solution of 6.6 g (0.06 mol) of sodium fluoroborate was combined with the solid and stirred for 0.5 hr. The reaction mixture was filtered, and the precipitate was washed with ether to yield a gray solid. Recrystallization from acetone–ether afforded 3.4 g (26%) of a pale purple solid: mp 160–161°; ir (KBr) 1630, 1600, 1584, 1491, 1422, and 1130–1010 cm^{-1}; nmr (deuterioacetone) 2.09 (s, 6 H), 6.25 (s, 1 H), and 7.2–7.6 ppm (m, 10 H). *Anal.* Calcd for $C_{15}H_{17}SBF_4$: C, 56.99; H, 5.43. Found: C, 56.57; H, 5.91.

Synthesis of Benzhydryldiethylsulfonium Fluoroborate (XIII).—To 10 g (0.11 mol) of diethyl sulfide in the flask was added 28 g (0.11 mol) of diphenylbromomethane. To the stirring suspension, 11 g (0.11 mol) of sodium fluoroborate aqueous solution was added. After stirring for 12 hr, the solution was filtered and the precipitate was washed several times with ether. Recrystallization from acetone–ether gave 13 g (29%) of a white solid: mp 115.5–117°; ir (KBr) 1580, 1485, 1445, 1410, 1255, and 1110–1020 cm^{-1}; nmr ($CDCl_3$) δ 2.03 (t, 6 H), 3.38 (m, 4 H), 6.11 (s, 1 H), and 7.6–7.9 ppm (m, 10 H). *Anal.* Calcd for $C_{17}H_{21}SBF_4$: C, 58.99; H, 6.44. Found: C, 59.33; H, 6.10.

Synthesis of Benzhydryldiisopropylsulfonium Perchlorate (XIV).—The salt was prepared as in the above method using 30 g (0.12 mol) of diphenylbromomethane, 22 g (0.18 mol) of diisopropyl sulfide, and 25 g (0.22 mol) of silver perchlorate. After 20 hr, the yield was 7 g (15%): mp 98–99°; ir (KBr) 1595, 1486, 1442, 1372, 1358, 1232, 1170, 1137, 1108, 1080, and 1022 cm^{-1}; nmr ($CDCl_3$) δ 3.11 (d, 12 H), 3.85 (m, 2 H), 5.40 (s, 1 H), and 7.1–7.9 ppm (m, 10 H). *Anal.* Calcd for $C_{19}H_{25}SClO_4$: C, 59.30; H, 6.50. Found: C, 59.18; H, 6.25.

General Procedure of Photochemical Reactions of Phenyl- and Diphenyldiazomethanes.—Photolysis of 0.4–2 mmol of phenyl- or diphenyldiazomethanes in 5–20 mmol of a substrate was carried out with a high-pressure mercury lamp in Pyrex vessels without degassing. After the diazo band disappeared from the ir spectrum of the reaction mixture, a known amount of an internal standard was added to the reaction mixture, which was then analyzed by gas chromatography. The structure of the isolated product was determined on the basis of nmr and ir spectra and elemental analysis. The cyclopropane derivatives obtained from the reaction with the allylic system consist of two geometrical isomers, but their configurations were not assigned. Analytical data are reported in Table IV.[26]

General Procedure of Cupric Sulfate Catalyzed Thermal Reactions.—Thermal reactions were carried out for 0.4–2 mmol of phenyl- or diphenyldiazomethanes in 5–20 mmol of a substrate in the presence of 20 mg of cupric sulfate. Samples were kept at room temperature or at 70° for the appropriate time. The results obtained are independent of the reaction conditions. The reactions in allylic sulfides were carried out at 110° because of slow reaction.

General Procedure of Thermal Reactions of Aryldiazomethanes.—A similar reaction on the same scale was carried out without cupric sulfate. More violent conditions are required to complete the reactions. Samples of phenyldiazomethane were heated at 140° and of diphenyldiazomethane at 70–110°. The products were examined by glpc.

Reactions of Benzhydryldialkylsulfonium Salts.—To a stirred suspension of 200 mg (5.1 mmol) of sodium amide in 10 ml of solvent was added, over a period of 10 min, 1.3 mmol of benzhydryldialkylsulfonium salt. The resulting solution was stirred for 20–24 hr. After addition, the reaction mixture was extracted with ether, washed with water several times, and dried over Drierite. The products were analyzed by glpc.

Photolysis of Phenyldiazomethane in Dimethyl Sulfide.—Irradiation of a cooled solution of 0.068 g (0.58 mmol) of phenyldiazomethane in 0.6 g (10 mmol) of dimethyl sulfide contained in a Pyrex vessel resulted in the evolution of nitrogen gas. After the infrared spectrum of the reaction mixture showed no diazo band, the reaction products were isolated by glpc using a Carbowax column. The yields shown already were determined by glpc analysis using internal biphenyl.

Photolysis of Diphenyldiazomethane in Dimethyl Sulfide.—A solution of 0.516 g (2.66 mmol) of diphenyldiazomethane in 1.65 g (26.6 mmol) of dimethyl sulfide was irradiated. The reaction mixture was analyzed directly by gas chromatography. The results are shown in Table IV.

Reaction of Phenyldiazomethane in Allylic Sulfides.—A solution of 0.064 g (0.54 mmol) of phenyldiazomethane in 1.00 g (9.82 mmol) of allyl sulfide was irradiated for 6 hr with a high-pressure mercury lamp. After distillation of solvent, the reaction mixture was purified by gas chromatography. Two major products were collected and characterized as shown in Table IV.

Reaction of Diphenyldiazomethane in Allyl Sulfide.—A solution of 76.9 mg of diphenyldiazomethane in 414 mg (4.1 mmol) of allyl ethyl sulfide was cooled with running water and irradiated through Pyrex for 15 hr with a high-pressure mercury lamp. Gas chromatography showed one major product, identified as XVIII-i.

Thermal Decomposition of Phenyldiazomethane in Allyl Sulfide.—A solution of 0.06 g of phenyldiazomethane in 1 g (10 mmol) of allyl ethyl sulfide was sealed in a Pyrex tube and heated to 140° for 5 hr. After removal of solvent the residue was chromatographed to yield one major product, XV-a.

Thermal Decomposition of Diphenyldiazomethane in Allyl Sulfide.—A solution of 223 mg of diphenyldiazomethane in 722 mg (7.13 mmol) of allyl ethyl sulfide was sealed in Pyrex tubes without degassing and heated at 110° for 1 hr. Analysis of the reaction mixture by gas chromatography showed two major peaks. The new products were tentatively identified by spectral analyses as insertion and addition products of diphenylcarbene to allyl ethyl sulfide.

Thermal Decomposition of Phenyldiazomethane in Allyl Sulfide in the Presence of Anhydrous Cupric Sulfate.—A solution of 0.075 g of phenyldiazomethane in 2 g of allyl ethyl sulfide with 20 mg of anhydrous cupric sulfate was sealed in a Pyrex tube and heated at 110° for 30 min. The reaction mixture was analyzed directly by gas chromatography.

Thermal Decomposition of Diphenyldiazomethane in Allyl Sulfide in the Presence of Anhydrous Cupric Sulfate.—A solution of 93 mg (0.48 mmol) of diphenyldiazomethane in 0.51 g (4.9

(26) Infrared spectra of these compounds will appear following these pages in the microfilm edition of this volume of the journal. Single copies may be obtained from the Business Operations Office, Books and Journals Division, American Chemical Society, 1155 Sixteenth St., N.W., Washington, D. C. 20036, by referring to code number JOC-72-3791. Remit check or money order for $3.00 for photocopy or $2.00 for microfiche.

mmol) of allyl ethyl sulfide and 20 mg of anhydrous cupric sulfate was sealed in a Pyrex tube and heated at 110° for 3 min. Analysis by infrared spectrum revealed that the reaction was over. Gas chromatography showed one major peak and one minor peak. Spectral analyses indicated that the major peak is the insertion product of the carbene into the carbon–sulfur bond, and the minor peak is the addition product.

Registry No.—IB-In, 35906-23-1; IB-r, 35906-24-2; IIA-In, 35906-25-3; IIB-In, 35906-26-4; IIIB-In, 35906-27-5; IIIB-E, 35906-28-6; VIIA-In, 35906-29-7; XII, 35906-30-0; XIII, 35906-31-1; XIII B-r, 35906-32-2; XIV, 35906-33-3; XV-a, 35906-34-4; XV-i, 35905-68-1; XVI-i, 35905-69-2; XVII-a, 35905-70-5; XVII-i, 35905-71-6; XVIII-a, 35905-72-7; XVIII-i, 35905-73-8; XIX-a, 35905-74-9; XIX-i, 35905-75-0; XX-i, 35905-76-1; XXI-a, 35905-77-2; XXI-i, 35905-78-3; phenyldiazomethane, 766-91-6; diphenyldiazomethane, 833-40-9.

Model Systems Related to Reactivity of Protein Sulfur Functions. I. The Effect of Hydrophobic Bulk on Acid Strengths of Alkyl-Substituted Benzenethiols and on Nucleophilicities of the Benzenethiolate Anions toward *N*-Ethylmaleimide[1]

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Received March 29, 1972

Apparent acid dissociation constants of a series of alkyl-substituted benzenethiols in 95% ethanol are measured by the method of fractional neutralization. Thiol pK_a's correlate well with the pK_a's of the corresponding phenols. Electronic and steric substituent effects are separated (1) by comparison of para- and ortho-substituted isomers and (2) by a Hammett linear-free-energy correlation. The substantially lower acidity of 2-*tert*-butylbenzenethiol compared to the other benzenethiols studied is attributed to steric inhibition of solvation of the thiolate anion rather than to direct steric interactions between the *tert*-butyl group and the adjacent sulfur. The rates of addition of the alkyl-substituted benzenethiols to *N*-ethylmaleimide in 95% ethanol at 25° are reported. The rate of attack of ortho-alkyl-substituted benzenethiolate anion upon the olefinic double bond of *N*-ethylmaleimide is sensitive to the size or bulk of the alkyl group. Two effects are identified: (1) inhibition of solvation of the thiolate anion, which increases its nucleophilicity (rate accelerating), and (2) steric interference between the thiolate nucleophile and the olefin transition state (rate retarding). The first known example of net steric acceleration in a nucleophilic addition to an activated double bond is reported for *o-tert*-butylbenzenethiolate which is found to be an order of magnitude more reactive than the other alkylbenzenethiols studied. The implications of the results as regards hydrophobic bulk effects in enzymatic reactions involving mercaptide functions are discussed.

The specific modification of only the most reactive protein sulfhydryl groups with activated double bond reagents such as *N*-ethylmaleimide (NEM) and acrylonitrile has encouraged their use as probes of SH environment and catalytic involvement.[2] Although it is generally supposed that such factors as location in the three-dimensional protein structure, microscopic environment or neighboring group effect, and interaction with other functional groups determine the rates of SH addition across the double bond of NEM,[3] few studies to evaluate the relative importance of the various factors are available.[4] Furthermore, SH group acid strengths affect the differential nucleophilic reactivities of protein sulfhydryl groups with SH modification reagents. While thiol acid strength as a function of electrical substituent effects has been the focus of previous investigations,[5,6] the effects of hydrophobic bulk on thiol dissociation has remained relatively unexplored. The findings from several protein studies, which indicate that SH groups frequently lie in interior hydrophobic locations,[7,8] suggested that investigation of thiol acid strength and of thiolate nucleophilicity in reaction with NEM as a function of nearby hydrophobic bulk should contribute to the understanding of protein SH group reactivities. Thus, we now report pK_a and kinetic studies with a series of alkyl-substituted benzenethiols selected to assess steric effects on acidity and rates of addition to NEM.

Results

The series of thiols investigated included benzenethiol and its alkyl substituted derivatives: 4-methyl; 3-methyl; 2-methyl; 2,6-dimethyl; 4-*tert*-butyl; and 2-*tert*-butyl.

The solubility properties of the aromatic thiols dictated that the pK_a measurements be performed in 95% ethanol solvent, a medium which approximates more closely than does water the probable hydrophobic environment of many protein SH groups. The absolute pH values obtained in such a medium by the potentiometric methods are not subject to simple

(1) This investigation was supported in part by Grant No. GM 11094 from the Institute of General Medical Sciences, U. S. Public Health Service, and by Contract AT(04-3)-34, Project 102, of the U. S. Atomic Energy Commission; P. D. Boyer, principal investigator.

(2) L. Cohen in "Annual Review of Biochemistry," Vol. 37, P. D. Boyer, Ed., Annual Reviews, Inc., Palo Alto, Calif., 1968, p 695.

(3) J. F. Riordan and B. L. Vallee in "Methods in Enzymology," Vol. 11, C. H. W. Hirs, Ed., Academic Press, New York, N. Y., 1967, p 451.

(4) Quantitative estimates of the influence of some polar and steric reaction parameters on the rates of addition of cysteine derivatives to acrylonitrile in water have been reported: M. Friedman, J. F. Cavins, and J. S. Wall, *J. Amer. Chem. Soc.*, **87**, 3671 (1965).

(5) M. M. Kreevoy, E. T. Harper, R. E. Duvall, H. S. Wilgus, III, and L. T. Ditsch, *ibid.*, **82**, 4899 (1960).

(6) J. P. Danehy and C. J. Noel, *ibid.*, **82**, 2511 (1960).

(7) R. Cecil, "The Protons," Vol. 1, 2nd ed, H. Neurath, Ed., Academic Press, New York, N. Y., 1963, p 380.

(8) For example, in human hemoglobin the cysteinyl residue at G11 of the α subunit is inaccessibly located in the interior.[9] Cysteine G14 of the β chain is in the hydrophobic contact area between the α_1 and β_1 subunits, and only the sulfhydryl group at F9 protrudes into the medium.[9]

(9) M. F. Perutz, H. Muirhead, J. M. Cox, and L. C. G. Goaman, *Nature (London)*, **217**, 131 (1968); M. F. Perutz, *J. Mol. Biol.*, **13**, 646 (1965).