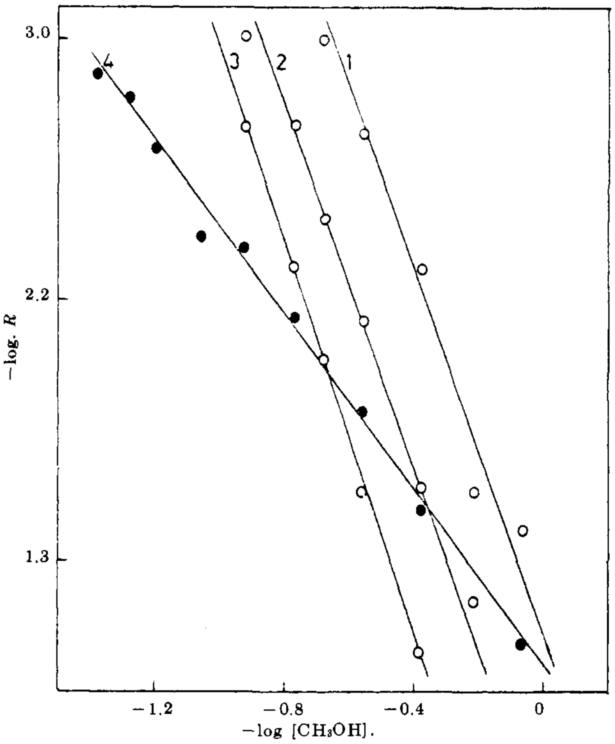

Fig. 2.—Order plots of logarithm of methanol concentration against logarithm of initial rate in methanol–dimethylformamide mixed solvent: (1) at 0°, slope −2.75; (2) at 15°, slope −2.75; (3) at 25°, slope −2.97; (4) methanol–dioxane mixed solvent at 20°, slope −1.33.

TABLE I

FIRST-ORDER RATE CONSTANTS FOR THE CYANOETHYLATION OF METHANOL IN DMF–METHANOL MIXTURES[a]

DMF, % by volume	10^3k_1 (min.$^{-1}$) at 0°	10^3k_1 (min.$^{-1}$) at 15°	10^3k_1 (min.$^{-1}$) at 25°
50	...	...	1.23
65	...	1.80	3.70
75	...	4.16	11.41
80	1.84	9.47	22.26
85	4.61	19.39	56.66
90[b]	10.80	64.36	187.75
93	50.83	164.29	...
95[c]	109.01	...	...

[a] Experimental conditions: initial concentration of acrylonitrile, 0.506 mole/l.; of lithium methoxide, 3.333 × 10^{-4} mole/l. Rate measurements were carried out as previously described.[1] [b] Under otherwise constant conditions, 10^3k_1 (min.$^{-1}$) values at various base concentrations, $10^4[CH_3OLi]$, shown in parentheses (moles/liter) were: 8.75 (0.83), 33.45 (1.67), 64.36 (3.33), 115.00 (5.00), 163.09 (6.67). [c] At low equivalent concentrations of methanol, polymerization of excess acrylonitrile occurs. See B.-A. Feit and A. Zilkha, *J. Appl. Polymer Sci.*, **7**, 287 (1963).

TABLE II

FIRST-ORDER RATE CONSTANTS FOR THE CYANOETHYLATION OF METHANOL IN DIOXANE–METHANOL MIXTURES[a]

Dioxane, % by volume	10^3k_1 (min.$^{-1}$) at 20°	Dioxane, % by volume	10^3k_1 (min.$^{-1}$) at 20°
0	2.31	75	15.81
20.7	3.57	85	29.27
34.5	5.11	90	56.61
51.7	8.42	93[b]	123.21
65	10.22	95	281.75

[a] Experimental conditions: initial concentration of acrylonitrile, 0.506 mole/l.; of potassium methoxide 6.720 × 10^{-3} mole/l. [b] Under otherwise constant conditions 10^3k_1 (min.$^{-1}$) values at base concentrations, $10^4[CH_3OK]$, shown in parentheses (moles/liter) were: 9.50 (8.33), 33.81 (20.00).

in the case of methanol–dimethylformamide solvent (containing 90% by volume of dimethylformamide) at 15°, and 1.1 in the case of methanol–dioxane (93% dioxane) at 20°. Negative values were found for the order of reaction in methanol (Fig. 2). In methanol–dimethylformamide mixtures, the order in methanol was approximately −3 at all three reaction temperatures, whereas in methanol–dioxane mixtures it was −1.3. It might well be assumed, therefore, that methanol itself participates in the reaction, for example, by solvation of the methoxide anions. An equilibrium involving free methoxide anions and solvated ones, the former being much more reactive, may exist: $CH_3O^- \cdot n\text{-}CH_3OH \rightleftharpoons CH_3O^- + n\text{-}CH_3OH$. Such an equilibrium followed by a rate determining nucleophilic attack[1] may be responsible for the negative order in methanol.

$$RO^- + CH_2{=}CH\text{-}CN \longrightarrow ROCH_2\text{-}\bar{C}H\text{-}CN$$

Support for the above can be found from the work of Cram, *et al.*,[4] on the sodium methoxide-catalyzed H–D exchange, where the reaction was 10^9 times faster in dimethyl sulfoxide than in methanol, due to a strong solvation of methoxide anions in methanol by hydrogen bonds, and a very poor one in dimethyl sulfoxide. Cavell and Speed[10] found a large increase in the rate of the isotopic exchange reaction of radioactive iodine with butyl iodide in mixed methanol–acetonitrile (ε 36) solvent, with increasing acetonitrile proportion. They too suggested that the existence of the equilibrium, $I^- \cdot CH_3OH \rightleftharpoons I^- + CH_3OH$, and the much greater reactivity of the free I^- as compared to the solvated one is responsible for this increase in rate.

The results of the present work offer possibilities for the shortening of reaction time and for obtaining higher yields in suitable nucleophilic additions.

(10) E. A. S. Cavell and J. A. Speed, *J. Chem. Soc.*, 1453 (1960); 226 (1961).

Oxidation of Thiols by Dimethyl Sulfoxide

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Various oxidizing agents such as nitric acid, hydrogen peroxide, oxygen, and potassium ferricyanide have been employed for the conversion of thiols to disulfides. However, most of these reagents are also capable of reacting with other oxidizable sites such as aldehyde and amino groups.

We wish to report a convenient laboratory synthesis of disulfides from the corresponding thiols by selective oxidation of the latter with dimethyl sulfoxide.

While most oxidizable functional groups are quite stable to dimethyl sulfoxide, there are several reports in the literature of its use as a unique oxidizing agent, for example, in the conversion of α-bromo ketones to gly-

TABLE I

Thiol used			Corresponding disulfides obtained						
				Crude product, yields and purity				Recrystallized product	
No.	Name	Purity, %	Name	Yield, by wt., %	Disulfide by analysis, %	(–SH), %	M.p., °C.	Obsd. m.p., °C.	Lit. m.p., °C.
1	Benzenethiol	100	Diphenyl disulfide	100	94.5	0.00	61–62	62–63	61
2	α-Toluenethiol	100	Dibenzyl disulfide	100	96.5	1.39	71–72	71–72	71–72
3	*o*-Aminobenzenethiol	100	Di-2-aminophenyl disulfide	80	[a]	14.8	91–92	94–95	93
4	*p*-Chloro-α-toluenethiol	100	Di-*p*-chlorobenzyl disulfide	97	96.8	0.45	53–55	56–57	58–59
5	*p*-Bromo-α-toluenethiol	99.6	Di-*p*-bromophenyl disulfide	100	95	0.04	92–95	95–96	93.8
6	*p*-Chlorobenzenethiol	99.7	Di-*p*-chlorophenyl disulfide	100	96.5	0.00	69–73	73–74	71.5
7	Mercaptoacetic acid	96.1	Dithiodiglycolic acid	100	92.0	0.63		105–108	107–108
8	3-Mercaptopropionic acid	99.9	3,3′-Dithiodipropionic acid	96	93.8	2.63	156–157	156–158	155
9	Pentachlorobenzenethiol	Tech.	Dipentachlorophenyl disulfide	80		4.60	223–227	235–237	229 and 235–237
10	1-Butanethiol	Tech.	Di-*n*-butyl disulfide	86	92.3	0.46	90[b] (3.7 mm.)	90.5[b] (3.7 mm.)	110–113[b] (15 mm.)
11	2-Diethylaminoethanethiol, HCl	98.3	2,2′-Diethylaminodiethyl disulfide, 2HCl	100	91.4	7.6	221–222	221–222	220–221

[a] End point not detectable due to color. [b] Boiling point.

oxals,[1] later modified for the conversion of alkyl halides and tosylates to their corresponding aldehydes.[2] In addition a number of higher molecular weight sulfides were found to undergo oxygen exchange with dimethyl sulfoxide to produce the corresponding sulfoxide.[3]

In their work on the bromination of amines and phenols in dimethyl sulfoxide Fletcher, *et al.*,[4] mention that increasing amounts of 48% hydrogen bromide with *p*-chlorothiophenol in dimethyl sulfoxide gave a crystalline product presumed to be the corresponding disulfide. There appears to be no further investigation of this finding. On the other hand, it is known that hydrogen sulfide can be oxidized to sulfur and water with dimethyl sulfoxide.[5]

In the present work it was found that when a thiol was dissolved in an excess of dimethyl sulfoxide and stirred for a maximum of eight hours at temperatures varying from 80–90°, the corresponding disulfides were obtained in excellent yield and purity. The present procedure is attractive not only for its simplicity and general applicability, but also because the dimethyl sulfoxide plays a double role of oxidizing agent and solvent.

In order to establish the oxidative function of dimethyl sulfoxide, several experiments using benzenethiol and α-toluenethiol were carried out under a nitrogen atmosphere. In both cases the yields of disulfide were identical with those obtained in Table I where air had not been excluded from the reaction. In addition the by-product of the reaction, dimethyl sulfide, was isolated and identified by its infrared spectrum. It should be mentioned that dimethyl sulfide could be reconverted to dimethyl sulfoxide by catalytic air oxidation in a larger scale process.

Experimental

General Procedure.—The apparatus consisted of an erlenmeyer flask fitted with an Agit-Therm Magnet stirrer, a water condenser, and a thermometer hung from the top of the condenser.

The thiol (0.1 mole) was dissolved in 50 g. of dimethyl sulfoxide. The resulting solution was stirred for 8 hr. at 80–90°. After that period of time the product solution was decolorized with charcoal and allowed to cool to room temperature. Further details are indicated in Table I.

For the isolation and purification of the disulfides the following three procedures were employed.

Procedure A for Solid Disulfides Insoluble in Water.—Examples are 1, 2, 3, 4, 5, 6, and 8 in Table I. The product solution was poured into a tenfold volume of ice–water and after 3-hr. standing, the precipitated disulfide was collected by filtration, washed three or four times with water, and dried under vacuum.

Procedure B for Disulfides Soluble in Water.—An example is 7 in Table I. The excess of the dimethyl sulfoxide was removed from the product solution by distillation under vacuum (3 mm.). In some instances, complete removal of dimethyl sulfoxide using this procedure was difficult and crystallization of the disulfides was inhibited.

Procedure C for Disulfides Forming a Separate Layer.—Examples are 9, 10 and 11 in Table I. The disulfide layer was collected in a separatory funnel, diluted with ethyl ether, and washed three or four times with water. The ethereal solution was dried over anhydrous sodium sulfate, the ether evaporated, and the product dried in a vacuum desiccator. In the case of example 9, the bispentachlorophenyl disulfide precipitated from dimethyl sulfoxide and was collected and washed with acetone. In the case of example 11, the product was partially soluble in dimethyl sulfoxide. The insoluble product was collected by filtration and the remainder precipitated by addition of ether. The combined precipitates were washed with ether and dried.

Purification.—Solid disulfides were recrystallized from ethyl alcohol–water, or ethyl acetate–benzene systems. Liquid disulfides were distilled under vacuum.

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(1) N. Kornblum, J. W. Powers, G. J. Anderson, W. J. Jones, H. O. Larson, O. Levand, and W. M. Weaver, *J. Am. Chem. Soc.*, **79**, 6562 (1957).

(2) N. Kornblum, W. J. Jones, and G. J. Anderson, *ibid.*, **81**, 4113 (1959); H. R. Nace and J. J. Monagle, *J. Org. Chem.*, **24**, 1792 (1959).

(3) S. Searles, Jr., and H. R. Hays, *ibid.*, **23**, 2028 (1958).

(4) T. L. Fletcher, M. J. Namkung, and H. L. Pan, *Chem. Ind.* (London), 660 (1957).

(5) N. Kharasch, "Organic Sulfur Compounds," Pergamon Press, New York, N. Y., 1961, p. 174.

The yields and purity of the crude disulfides were determined by weight and analytical methods.[6,7] Their disulfide and thiol contents were determined and the results are shown in Table I, along with melting points of the crude and purified disulfides.

Oxidation of Benzenethiol.—Two-tenths of a mole of benzenethiol was dissolved in 100 ml. of dimethyl sulfoxide and the solution was maintained at 85 ± 1°. Samples were removed at various intervals and analyzed for thiol and disulfide content.[6,7] The following conversions of thiol to disulfide were found: 85% after 30 min., 92.4% after 1 hr., 96.7% after 2 hr., 98.3% after 4 hr., and 98.9% after 6 hr.

Oxidation of Benzenethiol in the Absence of Air.—A 250-ml. three-necked flask was equipped with a magnetic stirrer, thermometer, a nitrogen gas inlet tube, and an outlet to a trap cooled in Dry Ice. The flask was charged with 11 g. (0.1 mole) of benzenethiol and 50 ml. of dimethyl sulfoxide under a blanket of nitrogen and the solution was heated with stirring at 80° for 18 hr. with a continuous flow of nitrogen through the system. The disulfide isolated in almost theoretical yield by procedure A weighed 10.8 g. and melted at 61–62°.

The liquid condensed in the Dry Ice trap separated in two layers. The upper one proved to be the expected dimethyl sulfide by infrared spectrum and boiling point; the lower layer was mainly water.

Similar results were obtained when the experiment was carried out with α-toluenethiol with the by-products being identified as dimethyl sulfide and water. The disulfide was obtained in 88% yield with m.p. 71–72°.

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[6] S. Siggia and R. L. Edsberg, *Anal. Chem.*, **20**, 938 (1948).

[7] J. W. Kimball, R. L. Kramer, and E. E. Reid, *J. Am. Chem. Soc.*, **43**, 1199 (1921).

The Jacobsen Rearrangement of 6-Methyl-7-propyltetralin[1]

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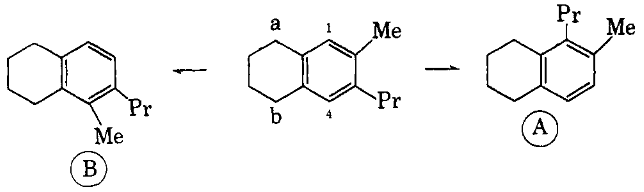
The Jacobsen rearrangement of 6-methyl-7-propyltetralin was initially investigated by Smith and Lo[2] who reported that a low yield (25%) of 6-methyl-5-propyltetralin was obtained. This result quite apparently was a surprise to the authors since they commented at some length on the mode of formation of this product. Clearly this is a result of considerable mechanistic implication. The starting material contains four alkyl substituents on the benzene ring which are *effectively all nonequivalent*. However, the differences among these four groups are quite subtle, particularly with respect to the *a priori* migratory aptitudes of the two alicyclic groups a and b. If A alone is the product either the propyl group migrates to C-1 or a migrates to C-4 or both occur. Since the product obtained is not the thermodynamically most stable one, it is appropriate to ask that the mechanism explain why the propyl group and/or a can migrate while the methyl and/or b cannot. This entirely unexpected migratory specificity prompted our interest in this case.



We have prepared a sample of 6-methyl-7-propyltetralin according to the procedure of Smith and Lo.[2] The hydrocarbon obtained in this way is impure and careful fractionation showed that it contained at least four other hydrocarbons. A sample of the purified 6-methyl-7-propyltetralin which was homogeneous as shown by gas partition chromatography analysis was subjected to the Jacobsen rearrangement. The hydrocarbon product was isolated in 28–30% yield and was shown to contain at least eleven substances. We have identified by comparison g.p.c. analysis five of these as 6-methyltetralin, 6-propyltetralin, starting material, 6-methyl-5-propyltetralin, and 5-methyl-6-propyltetralin. These latter two make up the major portion of the hydrocarbon product isolated, and are present in equivalent amounts. Thus, whatever the combination of migrating groups may be, it is now clear that we can derive no information about migratory preference from this experiment.

In the course of the synthesis of the starting material and of comparison samples of 6-methyl-5-propyl- and 5-methyl-6-propyltetralins we have had occasion to examine the products of partial reduction of several naphthalenes substituted in one ring. The reduction of β-methylnaphthalene gave 80% 6-methyltetralin, 10% of 2-methyltetralin, and 10% of methyldecalins. Similarly the reduction of 1-methyl-2-propylnaphthalene and of 1-propyl-2-methylnaphthalene gave about 70% of the product with the hydrogen added to the nonsubstituted ring. These results are in good accord with the findings of Hipsher and Wise,[3] though they used copper chromite while we employed Raney nickel.

Experimental

6-Methyltetralin.—2-Methylnaphthalene was reduced over Raney nickel according to the procedure of Fieser and Jones.[4] The product, b.p. 226–227°, n^{20}D 1.5350, was obtained in 70% yield. G.p.c. at 200° on a 6-ft. Carbowax 1500 column showed this to be a mixture containing an 8:1:1 ratio of two tetralins and isomeric decalins, respectively. Fractional distillation on a 30-in. Podbielniak Heli-Grid semimicro column gave a product, b.p. 130° (48 mm.), n^{19}D 1.5341, $\tilde{\nu}$ 800, 825 cm.$^{-1}$, 97% pure by g.p.c.

6-Methyl-7-propionyltetralin.—Samples of 6-methyltetralin (prepared as described above or by Clemmensen reduction of 7-methyl-1-tetralone[5]) were acylated according to the procedure of Smith and Lo.[2] The ketone was obtained as a clear oil, b.p. 150° (1.25 mm.), n^{23}D 1.5490–1.5510, in 70–84% yield, showing on g.p.c. analysis a broad peak partially separated into two peaks, but not sufficiently resolved to permit estimation of amounts of the components.

6-Methyl-7-propyltetralin.—Clemmensen reduction of 6-methyl-7-propionyltetralin as described by Smith and Lo[2] gave in 85–92% yield an oil, b.p. 94–99° (0.8 mm.), n^{20}D 1.5188–1.5284. This material showed two nearly resolved peaks using g.p.c., showing approximately a 5:1 ratio. The hydrocarbon was carefully fractionated on a Podbielniak Mini-Cal column to give 16 fractions. Fractions 11–16, b.p. 124° (6 mm.), n^{20}D 1.5294–1.5295, $\tilde{\nu}$ 865 cm.$^{-1}$ (m), were uniform as indicated by g.p.c.

Rearrangement of 6-Methyl-7-propyltetralin.—A 21.0-g. (0.11 mole) sample of the pure hydrocarbon was mixed with 125 ml. of concentrated sulfuric acid and rearranged as described by Smith and Lo.[2] Hydrolysis of the product with superheated steam at

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