

in ethanol-water mixtures that had stood for 13 half-lives or longer were recorded on a Cary 14 spectrophotometer. The concentrations of the styrenes were calculated using published extinction coefficients and λ_{max} values.⁴⁵⁻⁴⁷ In all cases styrene yields were less than 0.5%. No attempt was made to determine styrene yields in the acetone-water solvolyses.

(45) "Ultraviolet Absorption Spectrograms," API Research Project 44, National Bureau of Standards, Washington, D. C., 1945.

(46) K. C. Bryant, G. T. Kennedy, and E. M. Tanner, *J. Chem. Soc.*, 2389 (1949).

(47) H. A. Laitinen, F. A. Miller, and T. D. Parks, *J. Am. Chem. Soc.*, **69**, 2707 (1947).

Deuterium analyses were done with a Varian A-60 magnetic resonance spectrometer. Mixtures of about 1, 2, 3, and 4 mole % of the hydrogen compound in the deuterium components were prepared by weight. The nmr spectrum of each mixture was obtained in carbon tetrachloride. The ratio of the signal of the peaks in question to that of a nearby peak was determined by integration. A plot of these ratios vs. the apparent mole per cent yielded the true mole per cent of hydrogen with a precision of about 0.5%.

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Rates of Proton Exchange and Epimerization for *dl*- and *meso*- α -Methylbenzyl Sulfones

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Abstract: The ratio of the rate of deuterium exchange to the rate of epimerization for *dl*- and *meso*- α -methylbenzyl sulfones in methanol has been found to be 90:1 at 25°. This result confirms the relative insensitivity of the k_e/k_α ratio to substitution of Ph for R in MeCHR₂SO₂C₆H₅. It is concluded that [PhCMeSO₂R]⁻ carbanions are rapidly inverting (effectively planar).

The striking observation that the rate of base-catalyzed deuterium exchange for optically active *n*-HexCH(CH₃)SO₂C₆H₅ is much faster than the rate of racemization,³⁻⁵ which was made independently in three laboratories, has been rationalized by assuming the formation of asymmetric α -sulfonyl carbanion intermediates. Asymmetric α -sulfonyl carbanions having either a pyramidal or effectively planar structure will satisfy the experimental data, provided the proper assumptions are made.³ A number of sulfone systems have been examined in a series of ingenious experiments designed to allow a choice between a rapidly inverting or "effectively planar" α -sulfonyl carbanion intermediate with a barrier to rotation and a pyramidal α -sulfonyl carbanion intermediate with a barrier to inversion.⁶ The evidence obtained has been interpreted as favoring an effectively planar structure with racemization by rotation,⁶ but this interpretation has been challenged.⁷ In the course of another investigation we observed that the methyl groups in *dl*- and *meso*-C₆H₅CH(CH₃)SO₂CH(CH₃)C₆H₅ (**1** and **2**, respectively) exhibited different nmr chemical shifts. This offered a convenient method for measurement of the rate of base-catalyzed epimerization. It ap-

peared to be of interest to compare this rate with that of deuterium exchange, since we thought that the presence of the α -phenyl group would ensure near-planarity of the carbanion in this instance and that the change in k_e/k_α ratio might provide information concerning the structure of α -sulfonyl carbanions. While this work was in progress Corey and Lowry^{6c} reported that k_e/k_α did not change appreciably for C₆H₅*CH-(CH₃)SO₂C₆H₅ as compared to *n*-Hex*CH(CH₃)SO₂-C₆H₅. It seemed worthwhile, however, to check their result by an independent method. We, therefore, completed our study and present the results herein.

A mixture of **1** and **2** when treated successively with butyllithium and deuterium oxide gave the α, α' -dideuterated isomers,⁸ which were cleanly separated by column chromatography on silica gel into two diastereomeric forms melting at 89 and 140°. Unequivocal structures cannot be assigned to these on the basis of the information presently available. Examination of molecular models suggests that the *dl* isomer is more symmetrical and less sterically hindered. On this basis the higher melting isomer, which is also more strongly absorbed on the silica gel column, is tentatively assigned the *dl* structure. Equilibration with 0.5 *M* sodium methoxide in methanol at 25° for 7 days gave a mixture consisting of 55.6% of the 140° isomer and 44.4% of the 89° isomer (this corresponds to a 130-cal/mole difference in ground-state energy). Since structure assignment was not vital to the present work, resolution was not attempted.

Most of the rate measurements were made using the isomer melting at 89° since its greater solubility al-

(1) National Science Foundation Undergraduate Research Participant, summer 1965.

(2) National Institutes of Health Predoctoral Fellow, 1964-1966.

(3) (a) D. J. Cram, W. D. Nielsen, and B. Rickborn, *J. Am. Chem. Soc.*, **82**, 6415 (1960); (b) D. J. Cram, D. A. Scott, and W. D. Nielsen, *ibid.*, **83**, 3696 (1961).

(4) E. J. Corey and E. T. Kaiser, *ibid.*, **83**, 490 (1961).

(5) H. L. Goering, D. L. Towns, and B. Dittmer, *J. Org. Chem.*, **27**, 736 (1962).

(6) (a) E. J. Corey, H. Konig, and T. H. Lowry, *Tetrahedron Letters*, 515 (1962); (b) E. J. Corey and T. H. Lowry, *ibid.*, 793 (1965); (c) E. J. Corey and T. H. Lowry, *ibid.*, 803 (1965).

(7) D. J. Cram, R. D. Trepka, and P. St. Janiak, *J. Am. Chem. Soc.*, **88**, 2749 (1966).

(8) This result is comparable to that of C. R. Hauser and T. M. Harris, *J. Am. Chem. Soc.*, **81**, 1154 (1959), who found that benzyl sulfone reacts with potassium amide in liquid ammonia to give an α, α' -dideuterated carbanion.

lowed more accurate analyses. The rates of methoxide ion catalyzed exchange of the benzylic deuterium atoms with protons and the epimerization of the 89° isomer were carried out in methanol at various temperatures and are summarized in Table I.

Table I. Methoxide Ion Catalyzed Exchange and Epimerization Rates for α -Methylbenzyl Sulfones in Methanol

Isomer ^o	NaOCH ₃ , M ^b	Temp, °C ^c	k , ^d M ⁻¹ sec ⁻¹	E_a , kcal/ mole
89-D	5.69×10^{-1}	19.8	$7.2 \times 0.2 \times 10^{-4}$	20 ± 1
	5.58×10^{-1}	37.3	$5.0 \mp 0.1 \times 10^{-3}$	
		25.0 (1.31 × 10 ⁻³) ^e		
89-H	5.48×10^{-1}	47.0	$2.64 \mp 0.09 \times 10^{-4}$	25 ± 2
	5.40×10^{-1}	60.0	$1.25 \mp 0.03 \times 10^{-3}$	
		25.0 (1.46 × 10 ⁻⁶) ^e		
140-D	5.58×10^{-1}	37.2	$6.5 \mp 0.5 \times 10^{-3}$	
	7.18×10^{-2}	38.0	$(8.0 \times 10^{-3})^f$	

^o The letter designates the hydrogen isotope attached to the benzylic position. The deuterated species was used in the exchange work and the hydrogenated species was used in the epimerization study. ^b The base concentration was corrected for thermal volume changes (Handbook of Chemistry and Physics, 36th ed, Chemical Rubber Publishing Co., Cleveland, Ohio, 1954, p 2067). ^c The probable error is $\mp 0.5^\circ$. ^d The exchange rates have been statistically corrected by doubling the observed rate. ^e Extrapolated. ^f Check run; see Experimental Section.

The exchange:epimerization rate ratios calculated at various temperatures are 196 (0°), 90 (25°), 27 (72°), and 16 (100°). The value at 100° is close to the values of 10⁹ and 17⁶ for the k_e/k_a rate ratios of *n*-HexCH(CH₃)SO₂Ph at 100° in methanol. The value at 72° is somewhat lower than the value of 44 obtained for the k_e/k_a rate ratio of PhCH(CH₃)SO₂Ph at 72° in 2:1 EtOH-H₂O,^{6c} but the latter experiment was carried out in deuterated medium where the rate of exchange is increased by the amount of the k_H/k_D ratio and by the medium effect.

The present data confirm the relative insensitivity of the k_e/k_a ratio for RCH(CH₃)SO₂C₆H₅ sulfones.^{6c} The (extrapolated) exchange rate per proton for [PhCH(Me)]₂SO₂ in methanol at 100° (0.6 M⁻¹ sec⁻¹) is 10³ times that reported for HexCH(Me)SO₂Ph under these conditions,⁵ which agrees well with the reported value of almost 10⁴ for PhCH(Me)SO₂Ph *vs.* HexCH(Me)SO₂Ph.^{6c} It has been suggested that a maximum of two of the four powers of ten acceleration in the latter instance can be attributed to the conjugative effect of the phenyl group and that "less than half of the full electron-delocalizing effect of the phenyl group is felt in carbanion stabilization." It is true that rates of proton abstraction are not necessarily a good measure of carbanion stabilization,⁷ but pK_a values for a number of sulfones (measured in DMSO) are now available,¹⁰ and they indicate that the stabilization of an α -sulfonyl carbanion by a phenyl group is very large indeed. Thus, substitution of a phenyl group for the hydrogen atom of methyl sulfone causes a decrease of 7 pK_a units [$pK_a = 29$ for (CH₃)₂SO₂ *vs.* 22 for (PhCH₂)₂SO₂]. A value for a dialkyl-substituted sulfone of the type *n*-HexCH(Me)SO₂Ph is not yet available, but, judging

(9) D. J. Cram and A. S. Wingrove, *J. Am. Chem. Soc.*, **85**, 1100 (1963).

(10) F. G. Bordwell, R. H. Imes, and E. C. Steiner, *ibid.*, **89**, 3905 (1967).

from the increase of two pK_a units in changing from H-CH₂SO₂Ph to Me-CH₂SO₂Ph,¹⁰ the change from HexCH(CH₃)SO₂Ph to PhCH(CH₃)SO₂Ph should cause a decrease of at least 8 pK_a units. Therefore, the phenyl group causes very extensive delocalization of the negative charge in the α -sulfonylcarbanion.

Charge delocalization of this order of magnitude should greatly reduce the barrier to inversion for a pyramidal carbanion, and should result in a large increase in the rate of racemization (or epimerization), if this is the mechanism by which such processes occur. On the other hand, this electron delocalization requires that the phenyl group maintain a configuration wherein its π cloud is parallel, or nearly parallel, to the orbital of the carbanion. As a consequence in the carbanion the rotation around the C _{α} -SO₂ bond is restricted more for RCH(Me)SO₂R' when R = Ph than when R = Hex. This factor tends to retard the rate of rotation around C _{α} -SO₂ when Ph is substituted for Hex, and should decrease the rate of racemization. This effect is more than counteracted by the 10³-fold longer lifetime for the PhC⁻(Me)SO₂Ph and PhC⁻(Me)SO₂-CH(Me)Ph carbanions relative to the HexC⁻(Me)SO₂R' carbanion;¹¹ this should markedly increase the degree of racemization, since this depends on the relative rates of proton abstraction and rotation. The experimental observation is that the rate of racemization for PhCH(Me)SO₂Ph or epimerization for PhCH(Me)SO₂CH(Me)Ph is increased over HexCH(Me)SO₂Ph to the same degree (*ca.* 10³ to 10⁴) as is the rate of proton abstraction.¹² This result appears to be accommodated better by the representation of a rapidly inverting (effectively planar) asymmetric carbanion which racemizes relatively slowly because of a barrier to rotation, at least when R in RCH(Me)SO₂R' is phenyl. This representation requires removal of the proton so as to produce a carbanion in an asymmetric conformation; the proton must be returned on the same side of the molecule in order to account for exchange with retention of configuration.⁷ According to this view, racemization (or epimerization) occurs to the extent that rotation around the C _{α} -SO₂ bond to give a symmetric carbanion competes with proton abstraction from the solvent. Another possibility is that there is a competition between proton removal to produce an asymmetric carbanion and proton removal to produce a symmetric carbanion. According to this view, the k_e/k_a ratio would measure primarily the relative rates of proton removal to form asymmetric *vs.* symmetric carbanions.

Experimental Section¹³

***dl*- and *meso*- α -Methylbenzyl Sulfones.** A 20.0-g (82 mmoles) sample of mixed α -methylbenzyl sulfides, bp 121–131° (0.5–1 mm),¹⁴ was oxidized using a 4 M quantity of 30% hydrogen peroxide in acetic acid to give the mixed sulfones (92%). A 17.9-g sample in benzene was placed onto a 4 × 75 cm chromatographic column

(11) The relative rates of proton abstraction (k_{-1}) of the carbanion from methanol at 100°, calculated from the expression $k_{-1} = k_1 K_{(MeOH)}/K_{(sulfone)}$, are: HexCH(Me)SO₂Ph:[PhCH(Me)]₂SO₂ = 10¹⁰:10⁷.

(12) The rate of racemization for HexCH(Me)SO₂Ph in methanolic sodium methoxide at 100° is 2.6×10^{-6} M⁻¹ sec⁻¹ as compared to 7.2×10^{-2} M⁻¹ sec⁻¹ (extrapolated from Table I) for the rate of epimerization of [PhCH(Me)]₂SO₂.

(13) Microanalyses were by Micro-Tech, Skokie, Ill.

(14) P. Cagniant, G. Jecke, and P. Cagniant, *Bull. Soc. Chim. France*, 2225 (1961).

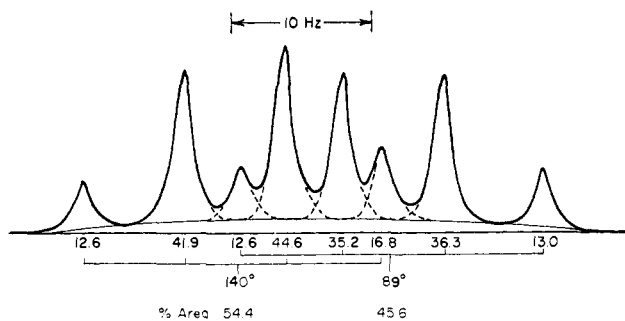


Figure 1. Equilibrium mixture of *dl*- and *meso*- α -methylbenzyl sulfones in methanol at 25°.

packed with silica gel and a 10% ether (by volume) in hexane mobile phase. After elutions with 1250 ml of 10% ether in hexane and 1250 ml of 15% ether in hexane, combined fractions of 500 ml of 15% and 1500 ml of 17.5% ether in hexane gave 8.64 g of material, mp 86–88°. After additional elutions with 500 ml of 17.5% and 500 ml of 25% ether in hexane, combined fractions of 1250 ml of 25% and 1000 ml of 50% ether in hexane and 1000 ml of ether gave 7.99 g of material, mp 136–139° (total recovery, 93%). After recrystallization from ether–hexane or ethanol the melting points were raised to 88–89 and 139–140° (lit.¹⁵ mp 135°). Both isomers exhibited strong sulfone absorptions in the infrared region: $\lambda_{\text{max}}^{\text{KBr}}$ 7.72 and 8.80 μ . The following nmr spectra (in ppm) were observed in deuteriochloroform: (89° isomer) 7.47 (singlet, 10.0 H), 4.00 (quartet, 1.9 H), and 1.65 (doublet, 6.1 H, $J_{\text{AX}} = 7.4$ Hz); (140° isomer) 7.48 (singlet, 10.0 H), 4.17 (quartet, 1.8 H), and 1.73 (doublet, 6.3 H, $J_{\text{AX}} = 7.2$ Hz).

Anal. Calcd for $\text{C}_{10}\text{H}_{16}\text{O}_2\text{S}$: C, 70.04; H, 6.61. Found (89° isomer): C, 69.88; H, 6.52. Found (140° isomer): C, 70.08; H, 6.68.

Equilibration of Isomers. A mixture (0.506 g) of *dl*- and *meso*- α -methylbenzyl sulfones was allowed to equilibrate for 7 days in 0.501 *M* sodium methoxide in methanol at 25.0°. At the end of this period the base was quenched with excess hydrochloric acid. The ethereal extracts were washed with water and dried over anhydrous magnesium sulfate. Removal of the ether left 0.481 g of white solid. The benzylic proton region of the nmr spectrum was expanded and integrated with a planimeter (Figure 1). The ratio of the areas of the two isomers was identical with that of a mixture prepared from 55.58% of the pure 140° isomer and 44.42% of the pure 89° isomer (Figure 2). (This ratio corresponds to a difference of 136 cal/mole in the energies of the ground states. An error of 1.5% in the percentage areas would give approximately a ± 30 -cal/mole deviation in the energies.)

Deuterated Sulfones. Commercial *n*-butyllithium in hexane (3.42 ml, 5.46 mmoles, 1.6 *M*) was delivered by a syringe into a solution of 0.5 g (1.82 mmoles) of mixed sulfones in 50 ml of 1,2-dimethoxyethane (dried over molecular sieves) kept at –20°. After stirring for 10 min deuterium oxide (0.5 ml, 25 mmoles) was added rapidly with a syringe. Dilute hydrochloric acid was added, and the mixture was extracted with methylene chloride. Chromatog-

(15) L. Bermejo and J. J. Herrera, *Anales Real Soc. Espan. Fis. Quim.*, **32**, 682 (1934); *Chem. Abstr.*, **29**, 3321⁴ (1935).

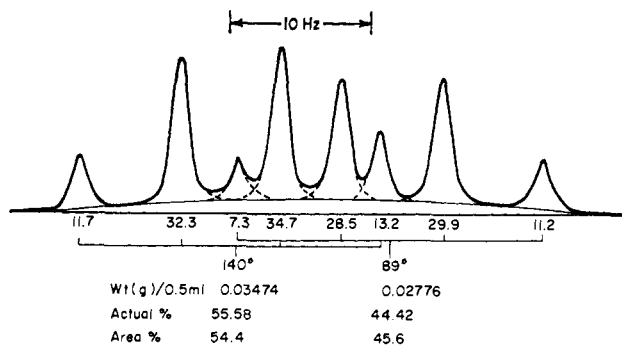


Figure 2. Standard mixture of *dl*- and *meso*- α -methylbenzyl sulfones.

raphy of 1.2 g from several runs gave 0.35 g of the 89° isomer and 0.29 g of the 140° isomer.

Kinetic Method. The nmr probe was set at the desired temperature by use of methanol and ethylene glycol standards. A saturated solution of the sample in methanol was used to fill the nmr tube about one-third full. The tube was then marked to contain twice the amount added and placed into the probe, whereupon the instrument was tuned (no adjustments were made after the run started). The nmr tube was then filled to the mark with standard base, which had been thermostated at the same temperature, shaken, and returned to the probe as quickly as possible. The peak heights (minus contributions from extraneous peaks) were obtained from the spectra. If time permitted, the reference peak (the phenyl group protons) was also scanned and the height of the observed peak was corrected by multiplying it by the ratio of the average height of the reference peaks to the height of the reference peak in question. The infinity values were obtained by plotting the peak heights *vs.* time, and extrapolating to infinity (ten half-lives).

For the exchange rates the decrease in the singlet methyl resonance of the deuterated species was measured. For the epimerization rates the decrease in the height of the high-field methyl resonance of the hydrogenated 89° isomer was measured. The pseudo-first-order rate constants were obtained by plotting $\log(h_{\infty} - h_t)$ *vs.* time (where *h* is the peak height). The slopes of the plots (linear for at least three half-lives) were multiplied by 2.303 and corrected for statistical factors in the case of the exchange rates. These rate constants were divided by the base concentration to give the second-order rate constants. (The concentration of the substrate was often greater than that of the base, but this did not affect the kinetics since the concentration of the base remained constant throughout the measurements.) The observed second-order rate constants are given in Table I.

In later related exchange studies the measurements were made by quenching aliquots from large samples kept in a constant-temperature bath. This method was more convenient, provided better temperature control, and permitted multiple integrations with averaging (details will be reported in a separate publication). A check run was made for the exchange of the 140° isomer (Table I).

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