bis alle Pteroinsäure ausgefallen ist. Die Säure wird abzentrifugiert, mit Wasser, Äthanol, Äther gewaschen und getrocknet (0,05 Torr, 80°, 6 Std.): 155 mg (81,2%) VI. NMR. (60 MHz, CF_3COOH): C(7)H: *S*, 9,17 ppm, 1 Pr; N(2')H_2: *br S*, 8,90 ppm, 2 Pr; Aromat. Pr: *AB*-System: $\delta_A = 8{,}58$ ppm, $\delta_B = 8{,}02$ ppm, $J = 8$ Hz, 4 Pr; C(9)H_2: *S*, 5,40 ppm, 2 Pr.

$C_{14}H_{12}N_6O_3$ (312,28) Ber. C 53,84 H 3,87 N 26,91% Gef. C 53,82 H 3,62 N 26,71%

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254. Base-Catalyzed Hydrogen-Deuterium Exchange in Sulfonium Cations[1]

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(8 V 71)

Summary. The effects of various structural changes on the kinetic acidity of protons alpha to a sulfonium function are reported. These effects are consistent with a transition state closely resembling a carbanion. Strong rate enhancements are observed for the 4-membered cyclic sulfonium cation but not for the other ring systems.

In 5-membered cyclic sulfonium cations the diastereotopic ring protons show high stereoselectivity towards abstraction by a base. Such stereoselectivity is diminished in going from D_2O to dimethyl sulfoxide-d_6-D_2O mixtures. By contrast no stereoselectivity is exhibited by the ring protons of the 6- and 7-membered cyclic sulfonium cations.

Although the rates for acyclic and cyclic sulfonium cations are closely similar, the activation parameters are characteristically different. It is suggested that solvation phenomena may be responsible for this behaviour.

The ability of sulfur (as well as phosphorus and silicon) atoms to stabilize adjacent carbanions is well known. This property manifests itself in the enhanced acidity, kinetic as well as thermodynamic, of hydrogen atoms in alpha positions to sulfur. The magnitude of the enhancement depends on the nature of the sulfur function and in general increases with the oxidation state of the sulfur atom. For example, the following order of kinetic acidity usually holds [1]: sulfide < sulfoxide < sulfonium cation < sulfone. This property is now frequently exploited in synthetic organic chemistry and has led to important synthetic methods (for reviews see [2]).

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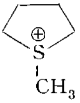
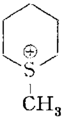
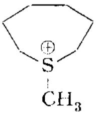
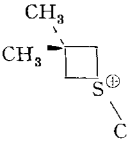
The most obvious application, however, is the easy deuteriation of the positions alpha to the sulfur atom by base catalysed hydrogen-deuterium exchange in D_2O.

In the course of an investigation on the NMR. spectral behavior of a number of cyclic sulfonium salts, we resorted to this deuteration procedure in order to simplify the spectra. In so doing we made a number of interesting observations on the rate of exchange as a function of ring size and other structural parameters, which we wish to communicate here.

Very few studies concerning the kinetic acidity of sulfonium salts are reported in the literature. The most comprehensive study on the rôle of the heteroatom in 'onium' salts is that of *Doering & Hoffman* [3], dating from 1955. However, only one sulfonium salt, trimethylsulfonium iodide, was investigated [3]. A more recent paper

Table 1. *Second-Order Specific Rates for Base-Catalyzed Deuterium Exchange of Alpha Hydrogen*

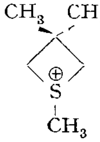
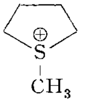
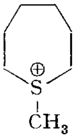
Compound	T, °C	$10^4\ k$ CH_3 $M^{-1}\ s^{-1}$	$10^5\ k$ CH_2 $M^{-1}\ s^{-1}$	E[a]) kcal/mole	$\log A$[a])
$(CH_3CH_2)_2S^{\oplus}–CH_3$ I^-	35	1.5	–		
	55	–	1.5		
	70	–	13	31.0	16.5
	80	–	44		
$(CH_3CH_2CH_2)_2S^{\oplus}–CH_3$ I^-	35	1.3	–		
	55	–	1.1		
	70	–	9.6	30.5	16.2
	80	–	33		
$[(CH_3)_2CH]_2S^{\oplus}–CH_3$ I^-	35	1.8	–		
	55	–	≤ 0.016[d])		
$[(CH_3)_2CHCH_2]_2S^{\oplus}–CH_3$ I^-	35	1.1	–		
	55	–	0.57		
 I^-	35	1.4	–		
	55	–	4.3[b])		
	70	–	18[b])	23.4	12.0
	80	–	62[b])		
 I^-	35	2.2	–		
	55	–	0.63		
	70	–	3.4	25.5	12.5
	80		11		
 I^-	35	0.92	–		
	45		1.8		
 c) BF_4^-	55		4.4	25.7	13.6
	65		19		
	35	230	–		

[a]) *Arrhenius* activation parameters for α-methylene hydrogens.
[b]) Only two hydrogens undergo exchange.
[c]) The compound decomposes with a first-order specific rate $5 \times 10^{-5}\ s^{-1}$ in NaOD 0.1 M.
[d]) Methine H.

reports data on the triethylsulfonium cation [1], while a third, still more recent paper reports only qualitative or semiquantitative observations on three sulfonium salts derived from the thiacyclohexane system [4]. We therefore feel justified in reporting our data which provide a wider experimental basis and allow a better understanding of the phenomenon. However, we consider this report as the starting point for future, more systematic investigations.

Results. – Tables I and II summarize the results obtained. The rate of hydrogen-deuterium exchange was determined in D_2O solvent under the catalytic action of NaOD. Decomposition (β-elimination) under the alkaline conditions required by the exchange was not a complicating factor as the exchange is a comparatively much

Table II. *Summary of Second-Order Rate Constants and Activation Parameters for Base Catalyzed Hydrogen-Deuterium Exchange at 35° in* D_2O a) b)

Compound	$10^6\ k\ CH_3$ $M^{-1}\ s^{-1}$	$10^7\ k\ CH_2$ $M^{-1}\ s^{-1}$	ΔH^* kcal/mole	ΔS^*, e.u.
$(CH_3CH_2)_2S^\oplus\text{—}CH_3\ I^\ominus$	5.0	1.9	30.4	+15
$(CH_3CH_2CH_2)_2S^\oplus\text{—}CH_3\ I^\ominus$	4.3	1.4	29.9	+13
$[(CH_3)_2CH]_2S^\oplus\text{—}CH_3\ I^\ominus$	6.0	<0.8 c)		
$[(CH_3)_2CHCH_2]_2S^\oplus\text{—}CH_3\ I^\ominus$	3.7	~0.7 d)		
 $BF_4^\ominus$	770	<2.5		
 $I^\ominus$ e)	4.6	20	22.8	− 6
 $I^\ominus$	7.3	1.2	24.9	− 3
 $I^\ominus$	3.1	12	25.1	+ 2
$(CH_3)_3S^\ominus$ $I^\ominus$	3.1 f)		22.4	− 1

a) Per hydrogen atom.

b) Except for the last entry in the table, the trimethylsulfonium compound, the activation parameters refer to the α-methylene hydrogens.

c) At 55°. Methine H.

d) Extrapolated from the datum at 55° using $E_a = 31$ kcal/mole.

e) Only *two* of the four hydrogens exchange. The minimum rate ratio between this pair and the other pair of hydrogens is 430 (at 55°).

f) Extrapolated from [3].

faster process. The rate was followed by NMR. spectrophotometry by determining as a function of time the decrease of the intensity of the resonances corresponding to the alpha hydrogens. These resonances are usually well separated in the NMR. spectrum since, beside aliphatic hydrogen atoms, the compounds comprise only one α-methyl group and two α-methylene groups. These have resonances at 2.8 δ and 3.3 δ respectively, *i.e.*, far downfield with respect to aliphatic protons (see Experimental).

Preliminary experiments confirmed that the exchange was a second-order reaction, first-order in OD^-. Usually the experiments were conducted in 5 M NaOD, although different concentrations were required occasionally to bring the reaction within a convenient time range. The rates reported in the Tables are second-order rate coefficients and are therefore normalized with respect to the concentration of the catalyst.

It is clear from the Tables that the α-methyl hydrogens exchange more rapidly than the α-methylene ones so that the exchange of the two sets of H's had to be studied in different temperature ranges. The results are compared at the same temperature, 35°, in Table II where the rates are also normalized with respect to statistical factors.

It is apparent from Table II that all α-methyl groups exchange their hydrogens at about the same specific rate, $3 - 7 \times 10^{-5} M^{-1} s^{-1}$, irrespective of the structural environment (with one very remarkable exception, that of 1,3,3-trimethylthietanium cation, which we shall discuss later). A similar observation has been reported by *Broaddus* for the exchange of the methyl hydrogens of various alkyl methyl sulfones [5]. Most likely our data are not sufficiently accurate to bring to light the minor structural effect that should result when the R groups in the R_2S^+–CH_3 cation are changed in the series R = Me, Et, *i*-Pr, *i*-Bu. Also the effect of any of these two groups is apparently indistinguishable from that resulting upon the inclusion of the sulfur atom in a 5-, 6- or 7-membered ring system. This is not surprising, however, since the polar effect of alkyl groups does not change much with the nature of the group itself (*Taft*'s σ^* values for primary and secondary alkyl groups are within a range of only 0.2 units [6]) and since the structural change considered here occur two single bonds away from the reaction center (the methyl group).

On the other hand, the strong polar effect displayed by the exchange reaction is evident from the already mentioned observation that the α-CH_3 hydrogens exchange faster than the α-methylene ones. In the diethylmethylsulfonium cation the rate ratio between these two types of alpha protons, corrected for the statistical factor 3/4, is 260. This value is only slightly smaller than that reported by *Broaddus* [5] for the exchange of sulfones, 330, and somewhat larger than that found at a higher temperature, 69.5°C, by *Julien* [1] between trimethyl- and triethylsulfonium iodides, 52, and between similarly substituted sulfoxides and sulfones: dimethyl- to diethylsulfone, 53; dimethyl- to diethylsulfoxide, 125. The effect of the alpha methyl groups is also of similar magnitude as that recently established by *Stirling* & *Redman* [7] in the *E1cB* elimination of phenoxide from ethyl phenyl ethers carrying an activating substituent such as Me_2S^+, $PhSO_2$ or PhSO on the beta position. Furthermore our results show that in the diisopropylmethylsulfonium cation, where two hydrogens have been substituted for methyl groups on the alpha carbon, a further decrease in rate is observed by at least a factor of 100 (at 55°). Numerous additional references on the effects of alkyl groups on carbanion formation can be found (see *e.g.* [8]).

Clearly these rate decreases are largely due to the electron releasing inductive effect of the methyl group with respect to hydrogen, which destabilizes the carbanionic transition state, and it is an obvious indication that in all these examples the transition state is very nearly equally advanced towards a carbanionic species and probably very close to it, as indicated by isotope effects. For the hydrogen-deuterium exchange of benzyl methyl sulfoxide, *Rauk, Wolfe & Czimadia* have reported for k_H/k_D a value of 1.4 [9], while values around unity have been reported by *Stirling* for *E1cB* elimination of β-substituted ethyl phenyl ethers when the β-substituent was either MeS(O) or Me_2S^+ [1b]. These small values are consistent with a transition state where the proton has been virtually completely transferred to a base [10]. This factor might also include a steric contribution. However, the fact that further substitution in the beta position (*n*-Pr and *i*-Bu compounds) brings about only a very minor decrease of the exchange rate for the methylene hydrogens, indicates that, at least up to this extent of branching, there is no appreciable steric effect neither for proton abstraction nor for solvation of the carbanionic transition state. Actually this rate decrease is so small that it is not even sufficient to account for the polar effects which the ethyl and the isopropyl groups can be expected to have (on the basis of the above discussed large effect of the methyl group with respect to hydrogen). We have no explanation for this inconsistency, except that our data are probably not accurate enough to disclose these small structural effects and that more accurate work is needed on a wider range of compounds in order to settle on these finer points.

A most remarkable structural effect is exhibited by the thietanium salt, whose S-methyl group displays a rate enhancement by over a factor of 100. This is all the more surprising in view of the insensitivity of the methyl hydrogen exchange rate to structural effects, as discussed above. While the exchange for this thietanium salt is accompanied by a concurrent base-catalyzed decomposition, there is no doubt about the reality of this rate acceleration. In fact the decomposition, although much faster than for the other sulfonium salts investigated here, was still slower, by a factor of about 500, than the exchange so that the latter could be measured easily[4]). On the other hand the phenomenon is not without precedent as *Cremer & Chang* have recently reported that the α-methyl hydrogens of a P-methyl phosphetanium cation exchange some 10^2–10^3 times faster than those of an acyclic methylphophonium cation [14].

A plausible explanation for this phenomenon is that it may be due to the type of hybrid orbitals that sulfur is forced to use in making this highly strained system.

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[4]) Contrary to the other sulfonium salts, the 1,3,3-trimethylthietanium fluoborate decomposes appreciably in the alkaline medium required by the exchange (0.01 M NaOD). However, the decomposition cannot be a β-elimination as there are no β-hydrogens. Available information indicates that the thietane ring system may react in a variety of ways with strong bases, including fragmentation to cyclopropanes [11] and ring expansion (in the case of thietane 1,1-dioxides) [12]. Evidence available to us indicates that in the present case ring opening occurs most easily under the influence of nucleophiles. For example, the 1,3,3-trimethylthietanium cation reacts with thiocyanate ion to give 2,2-dimethyl-3-(thiomethyl)-1-propyl thiocyanate [13].

Since the endocyclic bond angles are far smaller than 'natural' ones, in making the exocyclic bonds sulfur and carbon must use orbitals having a relatively high *s* character which are consequently more electronegative. This effect will also be felt by the methyl carbon which will be effectively more electronegative and accomodate more readily the electron pair of the incipient carbanion [15]. Although this effect operates in the desired direction, it would seem at first sight insufficient to account for all the rate acceleration. In cyclobutane the *ring-hydrogens* undergo exchange only 28 times faster than in cyclohexane [16]. Moreover, in the thietanium cation the α-methylene hydrogens should experience this effect much more readily than the exocyclic methyl hydrogens, while in fact they appear not to be affected. Perhaps this lack of effect is only apparent as there may be another concurrent rate-retarding effect (perhaps steric in origin) by the geminal β-methyl groups. Actually, preliminary evidence on another thietanium cation, 1-ethylthietanium fluoborate, which has no β-substituents, shows that it exchanges the alpha ring hydrogens very much faster than normal, *i.e.*, by a factor of about 10^5 with respect to the methylene hydrogens of an open chain sulfonium cation[5]. This very high exchange rate of the ring hydrogen atom renders more plausible the factor of 100 found for the exocyclic methyl hydrogens.

Whether or not the above explanation is valid, the same factors that cause the rate enhancement in the thietanium cation must also be operative in the phosphetanium cation [14]. In this connection it is very interesting that in a similar phosphetanium derivative, 1,2,2,3,4,4-hexamethyl-1-phenyl-phosphetanium bromide, the P^+-Me bond is 0.08 a shorter than normal [17], a fact consistent with the notion that phosphorus (and most likely sulfur) uses an orbital with high *s* character. It would be extremely interesting to obtain for these four-membered heterocyclic systems the appropriate ^{13}C-H coupling constants in order to assess the *s* character of the various C-H bonds [16] [18].

Further factors may play a role in determining the kinetic acidity of the S-CH_3 hydrogens in these small rings heterocycles. The finding by *Cremer* & *Chang* [14] that in 1,1,2,2,3,4,4-heptamethylphosphetanium bromide the P-Me group *trans* to the 3-Me group exchanges its hydrogens about ten times as fast as the P-Me group which is *cis* to the 3-Me group, indicates that configurational and conformational factors can be important. These authors [14] suggest that this difference stems either

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[5] Both the NMR. spectrum and the exchange behavior of 1-ethylthietanium fluoborate are very peculiar and deserve further study, which is being pursued. In D_2O the NMR. spectrum displays three regions of absorption centered at δ 3.50 (6H), 2.40 (2H) and 1.48 (3H). This latter region consists of two triplets ($J = 7$ cps) of unequal intensity, δ 1.46 and 1.50. Double irradiation of the 3.50 region changes the high field absorption into two singlets. The resonance at 3.50 consists of a complex broad multiplet, while that at 2.40 is a single, very broad absorption extending over 1 ppm. In the presence of NaOD 0.05 M the intensity of the 3.50 resonance decreases rapidly (initial second-order specific rate at 35°, 5×10^{-2} M^{-1} s^{-1}) to reach, after about one hour, a constant value corresponding to 2H. Thus only four of the six hydrogens undergo exchange. While the exchange occurs, the resonance at 2.40 progressively sharpens to reach a final half-band width of 0.2 ppm, which is still very large. Double irradiation at 3.50 after exchange, again modifies the 1.48 region to the same pattern of two singlets as before exchange, thus showing that this fast exchange involves exclusively the endocyclic α-methylenes and not the exocyclic one.

from steric hindrance to the approach of OD^-, or that d_π-p_π bonding is not independent of the geometrical disposition of the exchanging methyl group. This second explanation, however, is weakened by the circumstance that, while there is complete disagreement as to the importance of *d*-orbital participation [9b] [2c] [19] there is almost universal agreement on the lack of angular dependence of *d*-*p* overlap [3] [20][6]. Rather we should like to suggest that there may be a conformational reason for the differential exchange rate of the two methyl groups in *Cremer*'s phosphetanium salt [14] as well as for the rate enhancements prevailing in these four-membered heterocycles. In the small rings in fact, the puckering is necessarily slight (the dihedral angle in the previously mentioned phophetanium derivative is 24° [17]) so that there are strong 1,2 and 1,3 eclipsing interactions. The difference in compression energy between the original 'onium' salt and the quasi-ylid transition state cannot be predicted without elaborate calculations. However, it is not unconceivable that there may be enough release of steric strain (with respect to open chain or larger ring compounds) to account at least for a part of the rate acceleration.

Let us now turn to the ring hydrogens of the 5- to 7-membered cyclic compounds. Table II shows three remarkable phenomena. First, there appears to be a ring size effect, however small, since the 6-membered cycle reacts very nearly at the same rate as the open chain compounds while the 5- and the 7-membered cycles react faster by about one order of magnitude. Second, and most remarkable, the 5-membered compound exchanges only two of the four α-methylene protons, the second pair exchanging at least 400 times slower than the first pair [21]. As already reported, this result was attributed to conformational factors [21]. Having identified the exchanging protons as those *cis* to the methyl group (*trans* to the sulfur lone pair) and assuming a half-chair conformation, we have ascribed [21] the observed rate difference to the conformational energies of carbanions generated in a vertical transition state [9b] [22]. Recently published data on a thiolanium cation [23] support our conformational assignment. However, the validity of our discussion is questionable in the light of the recent finding by *Fraser, Durst et al.* [24] that the relative reactivity of diastereotopic protons in methyl benzyl sulfoxide [25] can be changed by altering the solvent base system (the extremes were 14:1 in D_2O/NaOD and 0.2:1 in *t*-BuOD/*t*-BuOLi, corresponding to an overall factor of 70 and a free energy difference of 2.5 kcal/mole [24]. A similar change in stereoselectivity had been found previously for a conformationally fixed sulfoxide [26]. These findings indicate the importance of solvation in determining the relative stability of carbanions, as well as the activation energy for proton abstraction, and consequently question the validity of our previous arguments [21] which were based on *Wolfe & Czimadia*'s theory [9b] [22] [27]. We feel, however, that these results, while detracting from the predictive value of this theory, are not incompatible with it. A solvent change, particularly for a strongly solvated molecule such as a sulfoxide in protic media, can substantially modify the relative energy of the various conformations of the ground state as well as those of the carbanion. Moreover the solvent may considerably affect the torsional angle in the prevailing ground state conformations and in this way have a sizeable effect on the conformational energy of the carbanionic transition state and on the free energy

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[6] *Op. cit.* [15], pp. 74–81, gives an excellent survey of both theoretical and experimental evidence.

of activation[7]. Thus we feel that *Wolfe & Czimadia*'s theory, with the provision that the solvent may play an important role, remains a sound basis for discussing the reactivity of diastereotopic protons, particularly when, as in our case, the reactivity difference is quite large. In this connection we think that our thiolanium cation may be a good model for testing the applicability of *Wolfe & Czimadia*'s theory since, beside the high stereoselectivity, reprotonation occurs exclusively with retention of configuration and the rigid system allows identification of the exchanging protons by means of nuclear *Overhauser* experiments[8]. We plan to investigate this system in the near future[9].

As to the 6- and 7-membered cyclic systems, a rationalization of the relatively small overall rate differences between them and with respect to the exchanging protons in the 5-membered cycle seems fruitless. It is worth noting, however, that the observed dependence of rate on ring size, $5 > 6 < 7$, is the same as that found by *Oae et al.* [8] in the exchange of cyclic thioacetals (1,3-dithiacycloalkanes) in *t*-BuOD/*t*-BuOK, and contrasts with the acidity sequence of 1,3-dithiacycloalkane 1,1,3,3-tetroxides studied by *Corey et al.* [30], which is $5 < 6 < 7$, and with the sequence $5 < 6$ as found by *Coffen et al.* [31], in the competitive lithiation of a bis-thioacetal containing one 5- and one 6-membered cycle. Since *Corey*'s [30] and *Coffen*'s [31] studies are designed to determine thermodynamic rather than kinetic acidities, as *Oae*'s and our studies do, it seems most likely to us that this conflict [2c] merely reflects differences in thermodynamic and kinetic acidities. Differences must be expected not only on the basis of much experimental work[10] which shows a lack of correlation between kinetic and thermodynamic acidity, but on theoretical grounds as well. In fact the relative conformational energies of the carbanionic transition states may differ substantially from those of the *equilibrium* carbanions [9b].

A remarkable observation is that in both 6- and 7-membered compounds *all four hydrogens* appear to exchange at the same rate. In these compounds there are two sets of diastereotopic protons which must be intrinsically different in their behaviour and react at different rates. In fact, in the closely related systems, *cis*- and *trans*-4-

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[7] *Cram et al.* [28] have recently discussed the stereochemistry of sulfonyl carbanion formation and collapse on the basis of the theory of *Wolfe & Czimadia* elaborated on the solvent effect.

[8] A test of this type has already been carried out by *Fraser & Shuber* [29] utilizing a conformationally frozen system, 1,11-dimethyl-5,7-dihydrodibenzothiepin, and has turned out against the theory [29b].

[9] Preliminary results indicate that the two diastereotopic protons remain neatly distinguishable in $(CH_3)_2SO/H_2O$ mixtures, in spite of the enormous rate increase and contrary to the finding relative to the six-membered sulfoxide [26]. In $(CH_3)_2SO/H_2O$ 50:50 *v./v.*, while the exchange rate increases by a factor of over 10^3, the higher field proton (the same as in D_2O) exchanges some 20 times faster than the lower field one. Even in 80% $(CH_3)_2SO$ the two protons show stereoselectivity. Although we could not measure the reactivity of both hydrogens, we estimate the lower limit of the rate ratio as about 10.
We are also investigating the 1,3,3-trimethylthiolanium cation, where the geminal protons at C-3 introduce a further bias towards half-chair conformation with maximum staggering at C3–C4 [21]. Preliminary results indicate that in this system the stereoselectivity of the geminal protons is even greater than in the unsubstituted compound. Moreover, the Me groups at C-3 appear to hinder somewhat the reactivity of the hydrogens at C-2 with respect to the hydrogens at C-5 (approximately a factor of 10).

[10] *Op. cit.* [15], Chap. 1, gives an excellent survey up to 1965; for subsequent work see [32].

phenylthiane 1-oxide, the two pairs of alpha protons exchange at different rates [26]. There may be two reasons for the lack of stereoselectivity in the 6- and 7-membered sulfonium cations: (i) the reactivity differences may be too small to be detectable with the NMR. analytical method; (ii) proton abstraction may be highly stereoselective but reprotonation occurs with inversion of configuration. In this latter case, since reprotonation is kinetically fast, all four protons would appear to exchange at the same rate.

The data of Table II allow one final observation concerning the reactivity of ring hydrogen atoms *versus* open chain ones. Although the rates of these two types of methylene hydrogens do not differ much, the activation parameters are widely different, a favorable (by 5–7 kcal/mole) activation enthalpy for the cyclic compounds being compensated by a large positive entropy of activation for the open chain ones. Our data are too limited for a sound statistical analysis of errors; however, an estimate can be made of the reliability of the activation parameters based on the accuracy and reproducibility of the kinetic data. A conservative estimate is that $\Delta H^{\neq}$ and $\Delta S^{\neq}$ are accurate to about 1.5 kcal/mole and 5 e.u. Even with these wide margins of error it is clear that the trend is real.

It is likely that this phenomenon does not reflect a gross change in mechanism, but is related to solvation. As the rate-determining step for exchange involves two oppositely charged ions, formation of the transition state should be attended by desolvation and consequently is expected to yield a net entropy increase [33]. That the cyclic systems do not exhibit such an increase is probably related to the greater opportunity for solvation of the incipient carbanion, due to the fact that the substituents are 'tied back'. However, a detailed explanation must await a systematic study of the rôle of solvent in these reactions.

Experimental. – *Materials.* With one exception, the sulfonium salts used in this work are known compounds. They were synthesized by methylation of the corresponding sulfides with methyl iodide according to standard procedures [34], and purified by repeated crystallization from ethanol. Their analysis and NMR. spectra were as expected and the m.p.'s agreed well with literature values. Only for 1-methylthietanium iodide was our m.p. 153–155° considerably higher than that reported, 141.5–142° [35].

3,3,1-Trimethylthietanium fluoborate was prepared by methylation of 3,3-dimethylthietane [36] with trimethyloxonium fluoborate in methylene chloride at –30° according to a tested procedure [37]. Recrystallized four times from acetone/methanol at –40°, m.p. 156–58° (uncorrected). In D_2O the NMR. spectrum exhibits very sharp singlets for the α-methylene protons (δ 3.80) and α-methyl protons (δ 3.25). The β-methyl protons give rise to a broad singlet (δ 1.45) whose width indicates $\Delta\nu \leq 1.5$ Hz (at 60 MHz). These features closely resemble those recently reported for the corresponding sulfide and sulfone [38] rather than those of the sulfoxide [38], the methoxysulfonium cation or the sulfilimine [38b], insofar as the four α-methylene protons give rise to a singlet (which remains sharp also at 100 MHz). It is also worth noting that the resonances for the α-protons occur at significantly lower field than those of the other sulfonium cations (see below).

$C_6H_{13}BF_4S$ Calc. C 35.2 H 6.42 F 37.2 S 15.7% Fd. C 35.9 H 6.59 F 36.8 S 15.4%

Kinetics. The kinetics were measured by NMR. spectrophotometry, following the decrease of the integrated intensities of the resonances of the α-protons which was checked against the increase of the H_2O peak intensity. The $^+S—CH_3$ proton resonance occurs in the range 2.7–3.0 δ while that of the $^+S—CH_2—$ protons occurs at 3.2–3.5 δ. The resonances of the β- and/or γ-protons, which occur at considerably higher field, were used as internal reference of concentration.

The samples were prepared by weighing the sulfonium salt in the NMR. tube, while the appropriate amounts of D_2O and NaOD were added in a dry box under an atmosphere free of moisture and carbon dioxide. Usually the concentration of the base was 5.0 M and that of the sulfonium salt 1.0 M, although lower concentrations of base were occasionally used as required for convenient rate measurements. The experiments at 35 ± 1° were conducted by placing the sample tube in the thermostatted cavity of the NMR. spectrophotometer. At higher temperatures, the sealed NMR. tube was placed in a thermostatted (± 0.1°) bath, chilled at the required time and measured at 35°.

Under the strong alkaline conditions required for the exchange, the sulfonium salts were observed to decompose after very long reaction times. However, in every case the decomposition rate was negligible with respect to exchange. Although it seems likely that the major decomposition arises from β-elimination, no effort was made to investigate the nature of the decomposition products (see also footnote 4).

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255. Komplexe mit makrocyclischen Liganden, II[1]). Zweischrittmechanismus bei der Komplexbildung von Cu^{2+} mit *meso*-5,7,7,12,14,14-Hexamethyl-1,4,8,11-tetraazacyclotetradecan

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(13. III. 71)

Summary. The complex formation between Cu^{II} and the title compound (teta) is studied by spectrophotometry and pH-stat techniques. Between pH 4 and 5,5 the reaction proceeds in two steps, the first giving a blue intermediate, $Cu(teta)^{2+}$ (blue), exhibiting a broad absorption band at 620 nm. Titration with NaOH and the absorption spectrum suggest that, in the intermediate, Cu^{II} is coordinated to only two amino groups of the ligand. Both steps are slow compared to other complex formation reactions of Cu^{II}. The rate of the first step, in which $Cu(teta)^{2+}$ (blue) is formed, is given by $v_1 = k_1 \cdot [Cu^{2+}]\,[(teta)H_2^{2+}]/[H^+]$ with $k_1 = 2{,}7 \cdot 10^{-6}\ s^{-1}$ at 40° and $I = 0{,}1$. In the second step the last two nitrogens of the quadridentate ligand are bound to Cu^{II}, giving the mauve end product. The rate of this step is given by $v_2 = k_2 \cdot [Cu(teta)OH^+ \text{ (blue)}]\,[OH^-]$ with $k_2 = 1{,}2 \cdot 10^3\ M^{-1}\ s^{-1}$ at 50° and $I = 0{,}5$.

Die Kinetik der Komplexbildung zyklischer aliphatischer Polyamine mit Schwermetall-Ionen wurde nur in wenigen Fällen studiert [1] [2] [3]. Dies liegt hauptsächlich daran, dass diese Komplexbildner bis vor kurzem nur schwer zugänglich waren. Heute lassen sich derartige Tetraamine entweder durch die von *Stetter & Mayer* [4] beschriebene Zyklisierung oder durch Templatreaktionen [5] synthetisieren.

Die Komplexbildung mit diesen Liganden ist viel langsamer [1] [2] [3] als mit den analogen offenkettigen Tetraaminen. Dies kommt daher, dass die Makrocyclen weniger flexibel sind, wodurch entweder die bei den offenkettigen Polyaminen beobachtete stufenweise Desolvatisierung des Metall-Ions nicht mehr möglich oder die Herstellung der ersten koordinativen Bindung nicht mehr allein geschwindigkeitsbestimmend ist.

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[1]) 1. Mitteilung: s. [1].