and error, at the following expression for D_{RMS}

$$D_{\rm RMS} = (X_0 / \Delta X)^{1.5} (10 + 46 / (N - 4.5))\epsilon_i$$
(33)

This is purely empirical and only approximate, the D_{RMS} values calculated from the equation differing from those obtained above by amounts up to 30%, expecially at large N. It is valid for X_0 greater than 1 and the dependence on ϵ_i is exact. Equation 33 shows that the larger ϵ_i , the larger D_{RMS} . Similarly, the smaller the range of acidities over which measurements are made, that is, the smaller ΔX , the larger $D_{\rm RMS}$ becomes. These conclusions simply reflect the fact that it is more difficult to detect curvature in a plot, the shorter the segment of the curve taken and the greater the experimental uncertainty in the data. The dependence on X_0 is reasonable, greater uncertainties being expected for the greater extrapolations needed for weaker bases. Finally, the dependence on N is reasonable. At low N, curvature would be hard to detect. Increasing N makes curvature easier to detect (that is, reduces $D_{\rm RMS}$), but beyond N equal to about 20 there is little further improvement.

 $D_{\rm RMS}$ can be taken as an estimate of the indeterminate constant defined in the earlier work.³ Clearly it is only a probabilistic estimate in the sense that there is a significant probability that it can be as large as $D_{\rm RMS}$. In a given case it could be larger or smaller. However, in a given case, the actual value of the constant remains unknown, indeterminate.

The analysis given here might seem appropriate as a basis for actually estimating the uncertainty in pK. However, a word of caution is in order. It is assumed throughout that the base under study is a second-order base. Third- and higher-order bases would be expected to generate similar conclusions but with different equations. There would be no way of knowing which order best describes a given base. There is also the well-recognized problem of solvent effects. These can add curvature to data but they may also cancel curvature. Reducing solvent effects by limiting the range of acidities used in counterproductive as eq 33 illustrates.

That the indeterminate constant exists and that it is substantial now seems well proven. How important is the results? The pKof acetic acid has been determined to $\pm 0.001 \ pK$ units.^{9,10} Instructions for measuring pK's of weak acids yielding results with

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an uncertainty of ± 0.02 units can be found in physical chemistry laboratory manuals. By comparison, an uncertainty of, let us say, ± 2.0 units seems outlandish, especially when one realizes that this represents an uncertainty in the K itself of a factor of 100. Excess acidity methods clearly fail to give a reasonable estimate of pK values.

The results presented here can be characterized as negative, casting a doubt as they do on an existing method for determining pK values. However, since the uncertainties are, and always have been, inherent in the method, presenting the limitation of the method is certainly useful. Since the analysis presented here did not consider the case of third- or higher-order bases and since it did not account for solvent effects or systematic uncertainties in the concentration of the hydrogen ion in strong acid, it is only indicative of possible magnitudes of uncertainties. For even if real curvatuve were detected in the data, there is no reliable way of deciding the source of the curvature. For these reasons, I am somewhat pessimistic about the possibility of ever improving the method, short of determining the function for eq 4 for all acidities for each base of interest. And although much work has been done on determining activity coefficients;11 these results seem to suggest that the form of eq 4 will remain elusive except, perhaps, in special cases (and excepting model systems where a form of one base is taken as being a good model for a different base).

The utility of acidity function methods for defining basicities of very weak bases is problematic. A common measure of basicity is the pK value. Any comparison of weak bases on the basis of their pK values, those values being determined by acidity function methods, should be considered meaningless, except perhaps in the case where the pK's differ by at least several units.

Finally, the foregoing analysis focuses attention solely on the uncertainty in the pK value taken as a thermodynamic property. It does not address itself to the possible utility of an excess acidity scale as an empirical scale nor to the possible utility of the constants derived from such a scale as empirical constants which can figure in empirical correlations. To be more in tune with the demands of rigor, it is suggested that the quantity determined by these methods and called pK be renamed pX and treated as an empirical parameter. pX is suggested to reflect the fact that the parameter is derived from the X scale and to reflect its unknown character.

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An FTIR Study of the Kinetics and Mechanism for the CI- and Br-Atom-Initiated Oxidation of SIH₄

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On the basis of FTIR product analysis of the UV-visible ($\lambda \ge 300 \text{ nm}$) photolysis of Cl₂-SiH₄ and Br₂-SiH₄ mixtures in 700 torr of N₂-O₂, both Cl and Br atoms were shown to exclusively undergo an H-atom abstraction reaction rather than a displacement reaction with SiH₄. The corresponding rate constants k{Cl+SiH₄} and k{Br+SiH₄} were determined at 298 K to be 4.4×10^{-10} and 1.0×10^{-13} cm³ molecule⁻¹ s⁻¹, respectively, by the competitive kinetic method with reference to the reactions Cl + C₃H₈ and Br + CH₂O. IR absorption bands attributable to an aerosol product were detected in the subsequent oxidation of the primary radical SiH₃. This product was tentatively identified as a polymeric form containing the [-HSi(OH)O-] group. A possible mechanism for its formation is discussed.

Introduction

While the Cl-atom reaction of alkane hydrocarbons has been the subject of extensive studies over the past several decades,¹ there is not much information on the corresponding reaction of their closest structural analogues, i.e., silanes (Si_nH_{2n+2}) . Namely, the only previous kinetic study of the Cl + silane reaction appears to be that of Schlyer et al.² for the Cl + SiH₄ reaction at room temperature using the discharge flow-resonance fluorescence

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method, i.e., $k{Cl+SiH_4} = (9.2 \pm 2.0) \times 10^{-11} \text{ cm}^3 \text{ molecule}^{-1}$ s⁻¹. Among other available kinetic data on elementary reactions of silanes are those involving H, D, I, and alkyl radicals.^{3,4} In all these cases, the Si-H series exhibits much greater reactivity than their C-H counterparts, due presumably to significantly weaker bond strengths and greater polarizabilities, and also to the availability of the d orbitals of silicon.³ In the Cl + SiH₄ reaction chosen for the present study, the possible occurrence of both H-atom abstraction and displacement channels must be considered, i.e.

$$HCI + SiH_3$$
(1a)

H + SiH₃CI (1b)

Reactions 1a and 1b are estimated to be exothermic by 13 and 17 kcal/mol, respectively.[3,5,6] There exists evidence for H-atom displacement reaction involving an Si-H compound; Cramer, Iyer, and Rowland⁷ observed a 7% yield of the product (CH₃)₂SiHF in the thermal ¹⁸F-atom substitution with (CH₃)₂SiH₂.

In the present study, the kinetics and mechanism for the Cl + SiH₄ reaction were investigated by the FTIR spectroscopic method of product analysis in the UV ($\lambda \leq 300$ nm) photolysis of Cl_2 -SiH₄-O₂ mixtures is diluent N₂. The presence of O₂ was an essential feature of the experimental design. Namely, preliminary results indicated that without the added O₂ the SiH₄ was highly susceptible to chain chlorination yielding all the SiH_xCl_{4-x} (x = 0-3) compounds even in the dark. Presumably, the chain reaction was sustained by the regeneration of Cl atoms either via reaction 1a followed by $Cl_2 + SiH_3 \rightarrow Cl + SiH_3Cl$, etc. or via reaction 1b followed by $Cl_2 + H \rightarrow Cl + HCl$, etc. Addition of O_2 to the Cl_2 -SiH₄ mixtures to scavenge SiH₃ or H proved to be an effective means for not only controlling the chain but also distinguishing the two possible mechanisms in terms of ensuing products. Thus, the nature of the Cl-atom initiated oxidation of SiH₄ was examined in some detail. In addition, for comparative purposes, the Br-atom reaction of SiH₄ was also studied in a similar fashion. Available thermochemical data ^{5,8} suggest that both H-atom abstraction and displacement channels for the Br + SiH₄ reaction are endothermic by 2 kcal/mol.

Experimental Section

General features of the FTIR system and the operational procedures have been described previously.^{9,10} In brief, a 50-cm long, 5-cm diameter quartz cell (1-m path length, double-passed, external mirrors) and a 3-m long, 15-cm diameter Pyrex cell (180-m path length, multipassed, internal mirrors) equipped with UV/visible ($\lambda \ge 300$ nm) fluorescent lamps (GE F40BLB or GTE F40/CW) were used as the photochemical reactors–IR absorption cells for reactant pressures in the torr and mtorr ranges, respectively. A KBr beam splitter–CuGe detector combination was used to record IR signals in the frequency region of 450–4000 cm⁻¹ with 1/16-cm⁻¹ resolution. IR spectra were derived from interferograms, ratioed against background and converted to absorbance.

Appropriate reference spectra were normally recorded in the 50-cm cell by directly monitoring sample pressures in the range of 0.1-1.0 torr prior to dilution with 700 torr of N₂ or air. Figure



Figure 1. Reference spectra of SiH₄, SiH₃Cl, and SiH₂Cl₂ in the frequency regions of 2100–2300 and 800–1000 cm⁻¹. Recorded in the presence of 700 torr of diluent air at $\Delta v = 1/16$ cm⁻¹, and displayed with identical absorbance scales for both regions.

1 illustrates some prominent spectral features of SiH₄, SiH₃Cl, and SiH₂Cl₂.¹⁰ Of these, both SiH₄ and SiH₂Cl₂ spectra were recorded from commercially available samples, while the SiH₃Cl spectrum was derived by spectral desynthesis from a composite spectrum containing various SiH_xCl_{4-x} (x = 0-4) spectra. Such mixtures were prepared by the chlorination of SiH₄ and SiH₂Cl₂ in the dark as mentioned earlier. The dark reactions between Cl₂ and the silanes, particularly SiH₄, occurred primarily during the process of introducing and mixing together the reactants in the photochemical reactors. This problem could be minimized but not completely avoided by prediluting the individual reactants with N_2 and O_2 prior to mixing and by occasional cleaning of the IR cells. Because of the potentially explosive nature of the SiH_4-O_2 mixtures, various precautionary measures were taken, and the reactant samples were handled and stored in small amounts. Once mixed in the reactors, the reactants were stable, at least for a period much longer than the typical irradiaton time of 1 min. Notably, mixtures containing Br₂ and SiH₄ were less susceptible to dark reaction, and the Br-atom-initiated reactions of SiH4 could be studied in both the presence and absence of added O_2 . Furthermore, the photolytic light sources used in the present study were effective in selectively photodissociating Cl₂ or Br₂. Namely, the reactant SiH₄ does not undergo photodissociation at $\lambda \ge 300$ nm,¹² while a reference reactant CH₂O employed for the competitive kinetic measurements had decay lifetimes of ≥ 1 h.¹³ Thus, the following kinetic and mechanistic data on the Cl (and Br) + SiH₄ reaction could be obtained without interferences from dark or photochemical depletion of the reactant mixtures.

Results and Discussion

Product studies in the photolysis of the $Cl_2-SiH_4-O_2$ system were made over a 100-fold variation in the reactant concentration and mixing ratio. Runs with low $[Cl_2]$ and $[SiH_4]$ in the mtorr range coupled with high $[O_2]$, e.g. 700 torr of air, were considered

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Figure 2. IR spectral data in the frequency region of 600-3700 cm⁻¹ from the photolysis of a mixture containing Cl₂ (5 mtorr) and SiH₄ (2 mtorr) in 700 torr of air. The absorbance signals were truncated at log $(I_0/I) = 1.52$.

a priori less susceptible to potential mechanistic complications arising from ill-defined secondary reactions. For instance, if H atoms are formed either by reaction 1b or by some secondary reactions, these conditions will ensure the predominant occurrence of $H + O_2(+M) \rightarrow HO_2(+M)$ over $H + Cl_2 \rightarrow HCl + Cl$ and $H + SiH_4 \rightarrow H_2 + SiH_3$.^{3,14,15} Moreover, the ensuing HO₂ radicals would form, at least in part, H_2O_2 via $2HO_2 \rightarrow H_2O_2$ + O_2 ,¹⁵ thus preventing the further occurrence of secondary free-radical reactions.

Figure 2 illustrates typical spectral data obtained under these conditions. Parts A and B of Figure 2 correspond to the spectra in the frequency region of 600-3700 cm⁻¹ recorded before and after 70 s of irradiation of Cl_2 (5 mtorr) and SiH₄ (2 mtorr) in 700 torr of purified air. It can be seen from the comparison of these spectra that the consumption of 1.0 mtorr of the SiH4 resulted in the formation of a nearly equimolar amount of HCl. H_2O_2 was detected in Figure 2B, but, as noted previously in the study of the self-reaction of HO216 it decayed rapidly to H2O on the reactor walls. The combined yield of H_2O_2 and H_2O was 0.43 mtorr. On the other hand, no evidence was obtained for the formation of the SiH₃Cl expected from reaction 1b. Its detection limit, S/N = 1, was estimated to be 2×10^{-3} mtorr, which corresponded to significantly less than 1% of the SiH4 reacted. Thus, these results indicate that reaction 1a is the predominant reaction channel and that the subsequent oxidation of the primary radical SiH₃ leads to the formation of the H₂O₂ and an Si-containing product described below.

Perhaps the most conspicuous feature of the product spectrum, Figure 2B, is the presence of very broad but well-defined bands centered at approximately 1120 and 3310 cm⁻¹. These and other broad bands are seen more clearly in Figure 2C which is a scale-expanded display of the residual spectrum derived from

Figure 2B by removing the spectral contributions of SiH₄, HCl. H_2O_2 , and H_2O_2 . On the basis of the following chemical and spectroscopic evidence, this residual spectrum was attributed to the formation of an aerosol product containing the [-HSi(OH)O-] group. First, according to the observed material balance, for every SiH₄ molecule reacted, one Si and approximately two H atoms were unaccounted for by the identified products HCl and H_2O_2 . Since this residual spectrum remained essentially unchanged under all the relevant experimental conditions employed, it is likely that all the bands belong to a single compound. Also, light scattering due to aerosol formation could be visually detected in runs with high reactant concentrations (in the 0.1-1.0-torr range). The spectrum contains various bands indicative of condensed phased H-bonded HO (3300 cm⁻¹), SiH (930 and 2200 cm⁻¹), and Si-O-Si (1120 cm⁻¹).¹⁷ The presence of HO and SiH groups was further verified by replacing the reactant SiH₄ with SiD₄. Namely, the major spectral changes upon deuterium substitution were the down shifting of the bands at 3310 and 2208 cm⁻¹ to 2490 and 1625 cm⁻¹, respectively. Also, with ${}^{18}O_2$ in place of ${}^{16}O_2$, the Si–O–Si asymmetric stretch band at 1120 cm⁻¹ was down shifted

by approximately 40 cm⁻¹. The preceding results clearly indicate that the observed aerosol product was formed in the oxidation of the primary radical SiH₃. Moreover, it is to be noted that the [-HSi(OH)O-] group is a polymeric form of the Si analogue of formic acid, i.e., HSi(O-H)=O. Apparently, nothing is known about this compound. However, as with cyclic or open-chain polymers containing siloxane SiR₁R₂=O (R₁ and R₂ = alkyl or aromatic groups),¹⁴ the HSi(OH)=O is likely to be unstable as a monomer and readily undergo polymerization. The following reaction scheme is consistent with the formation of this compound as well as other observed products:

$$SiH_3 + O_2 \rightarrow (adduct) \rightarrow (H_2Si(OH)O) \rightarrow HSi(OH)=O + H$$
 (2)

Evidence for the H-atom formation in this reaction was based on the observation that the stoichiometry $\Delta(\text{HCl})/\Delta(\text{SiH}_4)$ increased from approximately 1 to 2 with decrease in the mixing ratios of (O₂) to (Cl₂) and (SiH₄) from about 10⁴ to 1. Namely, in mixtures typically containing 0.5 torr each of Cl₂, SiH₄ and O₂ in 700 torr of N₂, the H atom reacted preferentially with Cl₂ rather than with SiH₄ or O₂ to yield an HCl in addition to that formed in reaction 1a. Note that the rate constants for the respective H-atom reactions are known to be about 2×10^{-11} , 4×10^{-13} , and 1×10^{-12} cm³ molecule⁻¹ s⁻¹ at 300 K and 700 torr of diluent pressure.^{3,14,15} On the other hand, in mixtures containing the reactants in the mtorr range in 700 torr of air, the H atom reacted exclusively with O₂ to yield an HO₂ which, in turn, lead to the formation of the observed product H₂O₂ via 2HO₂ \rightarrow H₂O₂ + O₂.¹⁵ The rate constant k{Cl+SiH₄} for reaction 1a was determined

The rate constant k{Cl+SiH₄} for reaction 1a was determined from the decay rates of SiH₄ relative to those of a reference reactant, C₃H₈, in the photolysis of mixtures containing Cl₂ and these two reactants in 10–50 torr of O₂ in N₂ with total pressure at 700 torr, by use of the integrated rate I. C₃H₈ was chosen

$$\frac{\ln \left[(\text{SiH}_4)_t / (\text{SiH}_4)_0 \right]}{\ln \left[(\text{C}_3\text{H}_8)_t / (\text{C}_3\text{H}_8)_0 \right]} = \frac{k\{\text{Cl} + \text{SiH}_4\}}{k\{\text{Cl} + \text{C}_3\text{H}_8\}} \tag{I}$$

as the reference instead of the more commonly used reference reactants (e.g., CH_2O and C_2H_6) because its reactivity was found to be much closer but still less than that of SiH₄. Note that the relative rate constants for the Cl-atom reaction of C_3H_8 , CH_2O , and C_2H_6 are approximately 3:1.5:1, respectively.¹⁵ In the present study, the relative decay rates of SiH₄ and C_3H_8 were measured as a function of reactant concentration and conversion in both the 50-cm and 3-m reactors; the results are summarized in Table I. For each run is listed only one pair of values for $[(SiH_4)_t]/[(SiH_4)_0]$ and $[(C_3H_6)_t]/[(C_3H_6)_0]$ measured most precisely at a relatively early stage of the reaction. The values of $k_1^2C_1+$

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TABLE I: Relative Rate Constants for the Cl-Atom Reaction of SiH₄ vs. C₃H₈^a

initial concn, mtorr			10 ³ (SiH ₄)./	$10^{3}(C_{1}H_{0})$,/	k{Cl+SiH}/
$(Cl_2)_0$	(SiH ₄) ₀	(C ₃ H ₈) ₀	(SiH ₄) ₀	$(C_{3}H_{8})_{0}$	$k[Cl+C_3H_8]$
 7.6	0.8	3.0	648 ± 6	840 ± 34	2.49 ± 0.59
7.6	1.6	3.4	631 ± 11	856 ± 20	2.96 ± 0.46
7.6	1.7	2.3	503 ± 9	755 ± 22	2.41 ± 0.26
7.6	2.3	4.0	652 ± 5	849 ± 17	2.61 ± 0.33
7.6	2.5	4.0	683 ± 4	871 ± 12	2.76 ± 0.28
850*	100	540	472 ± 3	774 ± 9	2.93 ± 0.13
850*	200	530	577 ± 4	833 ± 9	3.01 ± 0.19
850*	200	290	392 ± 4	723 ± 8	2.88 ± 0.10
					wt av 2.76 \pm 0.21 (σ)

^aDiluent contained 10-50 torr of O_2 in N_2 with total pressure at 700 torr. Irradiation time was 60-90 s. The 50 cm cell was used for runs indicated by asterisks, and the 3-m cell for all others. Formula for weighted average, see ref 18.

TADLE II. Relative Mate Constants for the Di-Atom Reaction of Shill 18, CI170	TABLE II:	Relative R	ate Constants f	or the	Br-Atom	Reaction	of SiH_	vs. CH ₂ O
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	initial concn, mtorr		10 ³ (SiH ₄)./	$10^{3}(CH_{2}O)./$	k{Br+CH_O}/
$(\mathrm{Br}_2)_0$	(SiH ₄) ₀	(CH ₂ O) ₀	(SiH ₄) ₀	(CH ₂ O) ₀	$k\{Br+SiH_4\}$
0.20	0.05	0.30	911 ± 11	330 ± 7	11.9 ± 1.6
0.30	0.16	0.30	850 ± 4	252 ± 2	8.5 ± 0.2
0.20	0.16	0.28	930 ± 10	387 ± 3	13.1 ± 2.0
0.20	0.21	0.21	908 ± 2	331 ± 4	11.5 ± 0.3
0.20	0.22	0.20	877 ± 8	237 ± 6	10.9 ± 0.8
0.20	0.31	0.15	765 ± 7	113 ± 3	8.1 ± 0.3
0.15	0.32	0.15	848 ± 7	253 ± 4	8.3 ± 0.4
					wt av $10.3 \pm 1.9 (\sigma)$

^a Irradiation time was 25-30 s. All the runs were made in the 50-cm cell with 700 torr of diluent N₂.

 SiH_4/k {Cl+C₃H₈} thus obtained are shown to be constant over a 100-fold variation in the concentration of both the reactants and ensuing products. Thus, these kinetic data as well as the preceding product data demonstrate the validity of the two mechanistic assumptions inherent to eq I, i.e., (1) depletion of the SiH₄ and C_3H_8 solely by Cl atoms and (2) no regeneration of these reactants in the secondary reactions. An absolute value of k{Cl+SiH₄} = $(4.17 \pm 0.48) \times 10^{-10}$ cm³ molecule⁻¹ s⁻¹ can be derived from an average value of 2.76 \pm 0.21 (σ) for this relative rate constant combined with $k[Cl+C_3H_8] = (1.56 \pm 0.06) \times 10^{-10} \text{ cm}^3 \text{ mole-}$ cule⁻¹ s⁻¹ measured directly by Lewis et al. using the dischargeflow-resonance fluorescence technique.¹ It should be noted that the present value of k{Cl+SiH₄} is roughly four times the value determined by Schlyer et al. using the discharge flow-resonance fluorescence technique.² This discrepancy could have arisen from an extraneous reaction either removing the SiH_4 in the present study or regenerating Cl atoms in the work of Schlyer et al. As discussed already, there was no indication of the former case, although it was not possible to rule it out completely. On the other hand, the latter possibility is also worth examining further. Schlyer et al. measured the decay rates of Cl atoms in large excess of Cl₂ and SiH₄ but no O_2 ² Thus, the primary radical SiH₃ might have reacted to a significant extent with the Cl₂ to regenerate Cl atoms, i.e., $SiH_3 + Cl_2 \rightarrow SiH_3Cl + Cl$. This should be rapidly verifiable with the use of much lower undissociated Cl_2 as commonly done in more recent discharge flow work.¹ At any rate, the $Cl + SiH_4$ reaction is one of the fastest H-abstraction reactions known to date and must proceed at a collisional rate with virtually zero activation energy. Note that the reaction diameter, d, calculated from the collision equation k{Cl+SiH₄} = $\pi d^2 [8kT/\pi\mu]^{1/2} = 4.2$ $\times 10^{-10}$ cm³ molecule⁻¹ s⁻¹ is 4.5 Å.

The rate constant k{Br+SiH₄} was similarly determined from the decay rates of SiH₄ relative to those of a reference reactant CH₂O in the photolysis of mixtures containing Br₂ and these reactants in the torr range in 700 torr of N₂. Addition of O₂ was

not required for this purpose, since the dark bromination reaction in this system proved to be negligible. Upon UV/visible ($\lambda \ge 300$ nm) irradiation, the SiH₄ decayed at much slower rates than the CH₂O. Nevertheless, the CH₂O was used as the reference, since the rate constant for the $Br + CH_2O$ reaction is reasonably well-established. The results obtained are summarized in Table II, from which an average value of k{Br+CH₂O}/k{Br+SiH₄} was determined to be 10.3 ± 1.9 (σ). An absolute value of k[Br+SiH₄] = $(1.05 \pm 0.29) \times 10^{-13}$ cm³ molecule⁻¹ s⁻¹ can be derived from this value combined with k{Br+CH₂O} = (1.08 ± 0.10) × 10⁻¹² cm³ molecule⁻¹ s⁻¹ at 298 K measured by Nava et al. using the flash photolysis-resonance fluorescence method.¹⁹ Thus, the rate constant for the $Br + SiH_4$ reaction is approximately three orders of magnitude smaller than that for the corresponding Cl-atom reaction at 298 K. It is likely, although not certain, that this difference is due primarily to significant activation energy for the Br-atom reaction, since both the Cl-atom and I-atom reactions of SiH₄ appear to have a similar A factor.⁴ As in the Cl + SiH₄ reaction, the H-atom abstraction channel was shown to be dominant over the displacement channel in the $Br + SiH_4$ reaction. Reaction products in the photolysis of the Br₂-SiH₄-O₂ system were analogous to those shown in Figure 2 for the comparable Cl₂-SiH₄-O₂ system. Namely, HBr was the only detectable Br-containing product, and the observed residual spectrum matched well that displayed in Figure 2C for the Si-containing aerosol product. These results can be readily explained by the occurrence of the primary step Br + SiH₄ \rightarrow SiH₃ + HBr followed by the oxidation of the SiH_3 , i.e., reaction 2.

Registry No. SiH₄, 7803-62-5; Br₂, 7726-95-6; Cl₂, 7782-50-5; Si-H₃Cl, 13465-78-6; SiH₂Cl₂, 4109-96-0; O₂, 7782-44-7.

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