weight value was approximately half (within ±8%) the value found in neutral salt solution.

That the polymer possesses an ordered helical structure was indicated by ultraviolet absorbance–temperature transition studies; poly d(I-C)·poly d(I-C) had a melting value (T_m) of 43° in 0.02 M sodium chloride solution (pH 7.2) and 54° in 0.1 M sodium chloride solution (pH 7.2). Ninety-five per cent of the absorbance transition occurred over a 3–5° range at both salt concentrations. For these studies the polymer was extracted with phenol and exhaustively dialyzed as previously described.[2d] Hence poly d(I-C)·poly d(I-C) has a considerably more stable structure than does poly dI·poly dC.[6] The molar extinction coefficient of poly d(I-C)·poly d(I-C) was 6.9×10^3 at the wavelength maximum (251 mμ) in 0.01 M NaCl–1×10^{-4} M EDTA (pH 7.0).

It is significant to note that the poly*ribo*nucleotide with alternating inosinic acid and cytidylic acid units is synthesized *de novo* by the *Azotobacter vinelandii* RNA polymerase[11] whereas poly dI·poly dC is synthesized *de novo* by the *Escherichia coli* DNA polymerase.[6a] Further properties of poly d(I-C)·poly d(I-C) as well as the formation of poly d(G-C)·poly d(G-C) are currently being studied.

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Catalytic Decomposition of Hydrogen Peroxide by Copper Chelates and Mixed Ligand Complexes of Histamine in the Presence of Phosphate Buffer in the Neutral pH Region[1]

Sir:

The catalytic decomposition of H_2O_2 to oxygen and water, *i.e.*, *catalatic reactions*, by metal salts and complexes has been extensively studied.[2] Catalatic activity is usually associated with catalase,[3] a hemoprotein, and iron compounds and chelates.[2,4–6] The nonheme, oxygen-carrying copper protein, hemocyanin, also exhibits catalatic activity[7–9] as do copper salts and chelates.[10–13] Many copper and iron complexes are also *peroxidatic; i.e.*, they promote the oxidation of hydrogen donors such as alcohols, phenols, and amines.[3,7,13d,14] Thus, the complex compounds of copper and iron provide relatively simple model structures for investigating the mechanisms of action of vitally important types of enzymes. However, for several reasons, no significant quantitative studies on catalatic reactions of copper complexes exist from which reaction mechanisms can be deduced. For example, previous investigations included various simplifying assumptions regarding the species of copper complexes present such as in 1:1 mixtures of Cu^{2+} and ligand, L, where it was arbitrarily assumed that no CuL_2 existed. Nor were the known[15] formations of hydrolyzed species taken into account, *e.g.*, LCuOH and $L_2Cu_2(OH)_2$. Experimentally, little or no attempt was made to maintain constant pH. In view of these oversimplifications, we are investigating catalatic systems involving copper and amino acids and related compounds in the pH region of ∼6–9 in sodium dihydrogen phosphate buffer. We have taken into account the formation of simple, mixed, and hydrolyzed complex species. In this report, employing histamine as the ligand, our data conform best to a combination of a free-radical and molecular mechanisms involving the 1:1 chelate of copper–histamine.

The rates of decomposition of H_2O_2 were determined from manometric measurements of O_2 by the use of a differential syringe manometer.[16] The reproducibility of our readings was ±5%, and the absolute accuracy as determined by measurement of known volumes of O_2 released from spectrophotometrically standardized solutions of H_2O_2 by crystalline catalase was ±4%. The rates of O_2 evolution were determined by presetting the micrometer syringe corresponding to a desired volume, generally from 3 to 20 μl, and the time required for the manometric fluid to reach the reference mark in a horizontal capillary was recorded. At this point the micrometer was reset for the next reading, etc., until the run was complete. The apparatus was maintained on a single station of a Warburg bath and the reaction reference flasks were completely immersed in the constant-temperature water bath. The rates of O_2 evolution were independent of shaking speeds above 80 cycles/min: a speed of 115 cycles/min was used throughout. Under the experimental conditions employed, only those solutions containing H_2O_2, copper, and histamine possessed significant catalatic activity.

In a series of experiments run at 25° and pH 7.0, we found that the over-all reaction rate, k_{obsd}, varied as the first power of the total molar concentration of copper ion, $[Cu^{2+}]_T$ and $[H_2O_2]_T$. In order to identify the cata-

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Table I. Catalytic Decomposition of H_2O_2 by Solutions of Copper Containing Histamine and Sodium Dihydrogen Phosphate[a]

			Concentration, M[b]						
pH	R, μl sec^{-1}	k_{obsd} × 10^9 l. mol^{-1} sec^{-1}	$[H_2O_2]_T$ × 10^2	$[HOO^-]$ × 10^6	$[CuHm^{2+}]$ × 10^4	$[CuHm_2{}^{2+}]$ × 10^4	$[CuHm(OH^-)^+]$ × 10^4	$[CuHm(HPO_4)]$ × 10^5	$[CuHm(HOO^-)^+]$ × 10^4
6.07	0.0976	3.99	6.66	0.195	2.68	0.300	0.313	3.17	1.47
6.60	0.12	4.91	3.33	0.33	1.66	0.881	0.663	4.61	1.55
7.04	0.15	6.14	2.00	0.55	0.940	1.42	1.03	4.04	1.45
7.57	0.25	10.2	1.33	1.25	0.382	1.87	1.42	2.11	1.32
8.16	0.25	10.2	0.667	2.40	0.123	2.16	1.78	0.747	0.830
8.66	0.30	12.3	0.667	7.26	0.0360	2.02	1.65	0.223	0.767

[a] $[Cu^{2+}]_T = 5.30 \times 10^{-4}$ *M*; $[Hm]_T = 1.06 \times 10^{-3}$ *M*; $[NaH_2PO_4]_T = 0.028$ *M*; 25.0°. [b] The concentrations of these and other species present in the solutions were calculated for the conditions employed using the following formation constants expressed as log K in parentheses and where Hm = histamine free base and $B^{3-} = PO_4{}^{3-}$: HHm^+ (9.88), H_2Hm^{2+} (16.01), $CuHm^{2+}$ (9.55), and $CuHm_2{}^{2+}$ (16.03) [B. L. Michel and A. C. Andrews, *J. Am. Chem. Soc.*, **77**, 5291 (1955)]; $Cu(OH^-)^+$ (6.5) and $Cu_2(OH^-)_2{}^{2+}$ (10.94) [D. D. Perrin, *J. Chem. Soc.*, 3189 (1960)]; $CuHm(OH^-)^+$ (7.0) and $Cu_2Hm_2(OH^-)_2{}^{2+}$ (11.8) [M. A. Doran, S. Chaberek, and A. E. Martell, *J. Am. Chem. Soc.*, **86**, 2129 (1964)]; HB^{2-} (11.6), H_2B^- (18.5), and H_3B (20.61) [G. Schwarzenbach and G. Geir, *Helv. Chim. Acta*, **46**, 906 (1963)]; H_2O_2 (11.6) [M. G. Evans and N. Uri, *Trans. Faraday Soc.*, **45**, 224 (1949)]; CuH_2B^+ (19.25) [J. Mercadie, *Compt. Rend.*, **221**, 581 (1945)]; CuHB (15.00) [H. Sigel, K. Becker, and D. B. McCormick, *Biochim. Biophys. Acta*, **148**, 655 (1967)]; H_2B-Cu-Hm (27.5), HB-Cu-Hm (22.7) [calculated from equation given in V. S. Sharma and J. Schubert, submitted for publication]; $CuHm(HOO^-)^+$ (6.45) [see text].

lytically active forms of Cu^{2+} and H_2O_2, we made a series of runs at different pH's, from pH 6.07 to 8.66, using a ligand to copper ratio of 2. The observed rates of O_2 evolution, R, in μl sec^{-1}, obtained from the *initial* slopes of a plot of microliters of O_2 evolved *vs.* time, were converted to k_{obsd} in units of mol^{-1} l. sec^{-1} after correcting the O_2 volume to 0° and 760 mm by the factor 4.09×10^{-8}.

The percentage of the total copper present in various species at different pH's was calculated on an IBM 360/50 electronic computer using a FORTRAN program[17] and the equilibrium constants cited in Table I.

In aqueous solution Cu(II) is tetracoordinate and shows little tendency to add more than four monodentate ligands or two bidentate ligands.[18] All of the simple, mixed, and hydrolyzed complex species taken into account are given in Table I. When evaluating rate-constant dependencies, some species could be disregarded. For example, histamine-free solutions containing cupric ions in buffer showed relatively little catalytic activity; hence the contribution of the following species are disregarded: $[Cu^{2+}]$, $[CuH_2PO_4{}^+]$, $[CuHPO_4]$, $[Cu(OH^-)^+]$, $[Cu_2(OH^-)_2{}^{2+}]$, as well as peroxide complexes such as $[Cu(HOO^-)^+]$.[19-21] In addition, $[CuHm(H_2PO_4)^+]$ is disregarded because it is not formed in significant amounts over the pH range studied.

From the data summarized in Table I, we calculated the *apparent rate constants*,[22] k', for various species as a function of pH. The formulation which best fit the experimental observations is given by

$$k_{obsd} = k_1'[CuHm^{2+}][HOO^-] + k_2'[CuHm(HOO^-)^+][HOO^-] \quad (1)$$

A plot of $k_{obsd}/[CuHm^{2+}][HOO^-]$ against $[CuHm(HOO^-)^+]/[CuHm^{2+}]$ gives a straight line for the pH range 6.07–8.16. The apparent rate constants with values of $k_1' = 50$ and $k_2' = 45$ were obtained from the intercept and slope, respectively, of the straight-line plot. The good fit of eq 1 to the experimental data indicates that the contributions of species other than $[CuHm^{2+}]$ and $[CuHm(HOO^-)^+]$ to the catalatic activity in the given pH range are relatively small. The relatively inactive species include $[CuHm(OH^-)^+]$, $[CuHm(OH^-)_2]$, and $[CuHm_2{}^{2+}]$. We also tested the observed rate data for a dependency on $[CuHm(HOO^-)^+][H_2O_2]$, but no significant correlation was found.

In the absence of information on the formation constant of the intermediate, $[CuHm(HOO^-)^+]$, we estimated it from measurements reported for ternary complexes of nickel involving HOO^- for which values of log $K \cong 4.5$–5.0 were obtained.[23] Since the formation constants of Cu(II) complexes are generally 1 to 2 log units higher than the corresponding nickel complexes, a value of log $K = 6.45$ for $[CuHm(HOO^-)^+]$ was used in our computations. The experimental data conform to eq 1 practically independent of the value chosen for log K of the intermediate, and, in fact, the value of k_1' remains nearly constant of the value chosen for log K of the intermediate. However, the value of k_2', the slope of the straight-line plot, is roughly proportional to the value of log K. It is obvious that an experimentally determined value of the formation constant needs to be made.

Equation 1 suggests that, in the neutral pH region, the decomposition of H_2O_2 by copper complexes may proceed by a combination of a molecular mechanism,[5c,10,13] in which a presumed intermediate species, $[CuHm(HOO^-)^+]$, reacts with $[HOO^-]$, and a free-radical mechanism involving reversible oxidation–reduction of a cupric–cuprous couple and the formation of free radicals, *e.g.*, HO_2 and OH, leading to a chain reaction.

Even though our experimental data give a remarkably good fit over a more than 100-fold range of hydrogen ion concentrations to the mechanism expressed in eq 1, we realize that alternative sequences of reactions may also fit the experimental data for such an inherently complicated process. The deviation observed at the highest pH investigated, pH 8.66, can be due to several reasons including oxidation of the ligand[14] and uncertainties regarding the nature and stability constants of the hydroxy, peroxy, and ternary copper species. A fuller formulation of the reaction mechanisms will be

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reported when we have completed additional chemical and physical measurements with a variety of mono-, di-, tri-, and tetradentate ligands.

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Lithiation of Trimethylsilyl Compounds

Sir:

Lithiation of tetramethylsilane by *n*-butyllithium in the presence of N,N,N′,N′-tetramethylethylenediamine (TMEDA)[1] has recently been reported by Peterson.[2] In work contemporaneous with Peterson's, we have observed lithiation of methyl groups in various organosilanes, with and without potentiating catalysts such as TMEDA.[3] Silylmethyl protons appear to be distinctly more acidic than methyl protons in hydrocarbons. Probably silicon, like phosphorus,[4] stabilizes the partial negative charge on attached CR_2Li groups by means of dative π bonding from carbon into low-energy unfilled orbitals of the Si atom.

Table I. Reactions

Silane (*M*)	*t*-BuLi,[a] *M*	TMEDA, *M*	Temp, °C	Reacn time	Products (% yield)[e]
Me_3SiCl (0.36)[b]	0.12	0.00	−78	2 hr	$Me_3SiCH_2SiMe_2Cl$ (33); Me_3SiCMe_3 (25); $Me_3SiCH_2SiMe_2$-*t*-Bu (10)
Me_3SiCl (0.2)	0.05	0.012	15–30	<1 min	$Me_3SiCH_2SiMe_2Cl$ (20); Me_3SiCMe_3 (20); $Me_3SiCH_2SiMe_2CMe_3$ (40)
Me_4Si (0.12)	0.1	0.025	25	4 days	$(Me_3Si)_2CH_2$[c] (40)
$(Me_3Si)_2O$ (0.22)	0.1	0.025	25	11 days	$Me_3SiCH_2Me_2SiOH$[d] (30)
$Me_3SiOCH_2CH_3$ (0.07)	0.03	0.008	25	2 days	$Me_3SiCH_2SiMe_2OEt$ (50)
Me_3SiOMe (0.2)	0.05	0.012	25	6 hr	Me_3SiCMe_3 (40); $Me_3SiCH_2SiMe_2OMe$ (15)
Me_3SiF (0.2)	0.05	0.012	15–30	<1 min	Me_3SiCMe_3 (85)
$Me_3SiOC(O)CH_3$ (0.2)	0.05	0.012	15–30	<1 min	$Me_3SiO(Me_3C)C{=}CH_2$ (65)

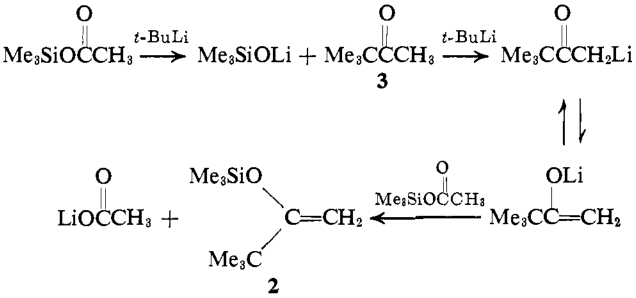
[a] The solution of *t*-BuLi (1.3 *M*, Foote Mineral) in pentane was added to a solution of the silane and TMEDA. [b] Equal volumes of THF and pentane used as solvent. [c] After derivatization with trimethylchlorosilane. [d] After aqueous work-up. [e] Yields are based on products obtained by distillation after removal of LiCl by filtration.

We now find that certain methylsilyl compounds can be metalated in the methyl group by *t*-butyllithium even when the silicon bears substituents highly reactive toward nucleophilic displacement. For example, trimethylchlorosilane undergoes lithiation by *t*-butyllithium at −78° in tetrahydrofuran, to give 33% $Me_3SiCH_2SiMe_2Cl$[5] (**1**) after work-up.

$$t\text{-BuLi} + Me_3SiCl \xrightarrow[\text{THF}]{-78^\circ} LiCH_2SiMe_2Cl \xrightarrow{Me_3SiCl} \underset{\mathbf{1},\ 33\%}{Me_3SiCH_2SiMe_2Cl}$$

A substantial amount of the coupling product of **1** with *t*-butyllithium, $Me_3SiCH_2SiMe_2$-*t*-Bu,[6] is also produced (Table I). Trimethylchlorosilane is also lithiated rapidly and exothermically by the *t*-butyllithium–TMEDA complex in pentane at room temperature. Under these conditions the metalation of tetramethylsilane requires several days, showing that the protons in Me_3SiCl are significantly more acidic than those in Me_4Si. Steric hindrance to coupling appears to be vital for lithiation of trimethylchlorosilane, for with *n*-butyllithium, either with or without TMEDA, trimethylchlorosilane gives exclusively the coupling product *n*-butyltrimethylsilane.[7]

Other electronegative substituents on silicon lead to variable and often unexpected results upon treatment with *t*-butyllithium–TMEDA (Table I). Trimethylfluorosilane gives exclusively the coupling product *t*-butyltrimethylsilane. The latter is also the principal product with methoxytrimethylsilane, along with a minor amount of the metalation product $Me_3SiCH_2SiMe_2OMe$.[8] However, *ethoxytrimethylsilane gives virtually exclusive lithiation* to yield ultimately $Me_3SiCH_2SiMe_2OEt$,[6] only a trace of coupling being observed. Thus the slight increase in steric requirement from the methoxy to the ethoxy compound changes the nature of the reaction completely. Acetoxytrimethylsilane yields 3,3-dimethyl-2-trimethylsiloxy-1-butene[6] (**2**) in a rapid reaction. The formation of this unsaturated product can be accounted for by the following reaction sequence.



Compound **2** is also formed when a pentane solution of *t*-butyllithium is added to an excess of *t*-butyl methyl ketone (**3**) and trimethylchlorosilane.

Hexamethydisiloxane and *t*-butyllithium give, after aqueous work-up, the unexpected silanol, $Me_3SiCH_2SiMe_2OH$, as the only significant product along with unchanged starting material. The reactions leading to formation of the silanol are not clear, but lithiation

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