3-carboxaldehyde, 1-naphthaldehyde, p-nitrobenzaldehyde, and anisaldehyde gave the corresponding 8-substituted theophyllines: 8-(3'-Indolyl)theophylline melted >360°. *Anal.* Calcd. for $C_{15}H_{13}N_5O_2$: C, 61.01; H, 4.44; N, 23.72. Found: C, 61.01; H, 4.44; N, 23.86. 8-(1'-Naphthyl)theophylline melted at 328–329°. *Anal.* Calcd. for $C_{17}H_{14}N_4O_2$: C, 66.65; H, 4.61; N, 18.29. Found: C, 66.70; H, 4.54; N, 18.36. 8-(p-Nitrophenyl)theophylline melted >360°. *Anal.* Calcd. for $C_{13}H_{11}N_5O_4$: C, 51.83; H, 3.68; N, 23.25. Found: C, 51.61; H, 3.69; N, 23.19. 8-(p-Methoxyphenyl)theophylline melted >360°. *Anal.* Calcd. for $C_{14}H_{14}N_4O_3$: C, 58.73; H, 4.93; N, 19.57. Found: C, 58.55; H, 4.97; N, 19.74.

By analogy with the preceding results, condensation of 1 with phenylglyoxal should have given 8-benzoyltheophylline, or perhaps the secondary alcohol formed by reduction of the carbonyl group with formic acid. However, the reaction took a completely unexpected course and gave 1,3-dimethyl-7-phenyl-2,4-(1H,3H)-pteridinedione (8)[6] and 1,3-dimethyl-4-amino-5-benzamidouracil (9) (m.p. 287–289°; ν_{max}^{Nujol} 3400, 3355, and 3200 cm.$^{-1}$. *Anal.* Calcd. for $C_{13}H_{14}N_4O_3$: C, 56.93;

(6) G. P. G. Dick, H. C. S. Wood, and W. R. Logan, *J. Chem. Soc.*, 2131 (1956).

H, 5.15; N, 20.43. Found: C, 56.97; H, 5.09; N, 20.23) in approximately equal amounts. The former compound must arise by initial reduction of 1 with formic acid to 1,3-dimethyl-4,5-diaminouracil, followed by condensation with phenylglyoxal (thus giving the 7-phenyl isomer exclusively),[7-9] while the latter compound apparently arises by initial condensation of the 4-amino group of 1 with phenylglyoxal followed by reduction of the nitroso group to the hydroxylamino stage, cyclization, dehydration, and deformylation.

During the course of this work it was noted that 1 behaved anomalously on heating. The compound decomposes at its melting point with copious evolution of brown fumes and the loss of its characteristic lavender color, but as the temperature is raised above the melting point the melt resolidifies to an orange solid which does not melt below 360°. We have identified the latter compound as the pyrimidopteridine 7 and suggest that it arises by a reverse-nitrosation reaction (which apparently can be either thermally or acid induced) to give 1,3-dimethyl-4-aminouracil, which then condenses with unchanged 1 to give 7.[10]

The many complex reactions undergone by the 4-amino-5-nitrosopyrimidine 1 under apparently straightforward conditions call attention to the possibility that similar complications may arise with other 4-amino-5-nitrosopyrimidines, which are ubiquitous intermediates for the synthesis of purines, pteridines, and other fused pyrimidine heterocycles.

(7) A. Albert, *Quart. Rev.* (London), 6, 227 (1952).

(8) W. R. Boon, *J. Chem. Soc.*, 2146 (1957).

(9) R. B. Angier, *J. Org. Chem.*, 28, 1398 (1963).

(10) M. Ridi, C. Pellerano, and E. Masi, *Ann. Chim.* (Rome), 53, 1717 (1963); *Chem. Abstr.*, 60, 10,684b (1964).

DEPARTMENT OF CHEMISTRY　　　　　　EDWARD C. TAYLOR
PRINCETON UNIVERSITY　　　　　　　　EDWARD E. GARCIA
PRINCETON, NEW JERSEY

A Nuclear Magnetic Resonance Study of a Carbonium Ion Exchange Reaction

Sir:

We wish to report that halide exchange occurs between covalent trityl halides and trityl cations and that the n.m.r. method readily provides data on the rates and mechanism of this exchange process.

The n.m.r. spectrum[1] of a methylene chloride solution of tris(p-tolyl)methyl chloride (I) exhibits sharp lines at -424.5 and -139.5 c.p.s. for phenyl and methyl protons while the carbonium ion tris(p-tolyl)methyl hexachloroantimonate (II) displays an A_2B_2 quartet centered at -457.5 c.p.s. (phenyl) and a singlet at -162 c.p.s. (methyl). The individual spectra are essentially independent of temperature and solvent, in contrast to a mixture of the two components.

Time-averaged, temperature-dependent methyl proton resonances of an equimolar mixture of I and II in methylene chloride are shown in Fig. 1. At 37° the sharp singlet is at precisely the chemical shift (-151 c.p.s.) expected for exchange averaging of the methyl protons of I and II and varies directly with the mole fraction of the constituents. As the temperature is

(1) Varian A-60 spectrometer; internal TMS.

Fig. 1.—Temperature dependance of methyl protons for equimolar mixture of I and II in CH_2Cl_2 solution.

lowered, the line broadens and splits symmetrically into two components. An analogous process occurs with the phenyl protons. An Arrhenius plot of the data[2] gives $E_a = 7$ kcal./mole from the methyl protons and 8 kcal./mole from the phenyl protons, the agreement falling within experimental error.

The exchange reaction (eq. 1) suggests a bimolecular mechanism and second-order kinetics. Equally pos-

$$Ar_3CCl + Ar_3C^+Y^- \underset{}{\overset{k_x}{\rightleftharpoons}} Ar_3C^+Y^- + Ar_3CCl \qquad (1)$$
$$\text{I} \qquad\qquad \text{II}$$

$$Ar = p\text{-}CH_3C_6H_4, \ Y = SbCl_6$$

sible is the S_N1-type process (eq. 2) which requires

$$Ar_3CCl \underset{k_r}{\overset{k_f}{\rightleftharpoons}} Ar_3C^+Cl^- \qquad (2)$$
$$\text{Ia}$$

$$Ar_3C^+Cl^- + Ar_3C^+Y^- \underset{}{\overset{k_{x'}}{\rightleftharpoons}} Ar_3C^+Y^- + Ar_3C^+Cl^-$$

first-order kinetics (k_f rate determining).[3] From differential line-broadening data we may distinguish between these alternatives.

Figure 2 illustrates this differential broadening for solutions containing different proportions of I to II at $-56°$. From the line half-widths (δ_f) one may calculate the lifetimes (τ) of both species using[6]

$$\frac{1}{\tau} = \pi(\delta_f - \delta_{f_0}) \qquad (3)$$

where δ_{f_0} is the half-width in the absence of exchange averaging. To discriminate between (1) and (2), expressions are derived for τ_I and τ_{II} using the general definition[6]

(2) H. S. Gutowsky and C. H. Holm, J. Chem. Phys., **25**, 1228 (1956).

(3) Both Swain[4] and Hughes[5] have demonstrated that exchange of tetra-alkylammonium radiohalide with trityl chloride in benzene follows first-order kinetics with rate independent of added radiohalide. The bimolecular mechanism (1) cannot, however, be excluded on this basis inasmuch as the acidity of carbonium vs. ammonium ion makes the bimolecular exchange reasonable for the former. Our assumption that in our low dielectric solvent (CH_2Cl_2) we are dealing primarily with solvated ion pairs, rather than free ions, followed the similar conclusion of Swain.[4]

(4) C. G. Swain and M. M. Kreevoy. J. Am. Chem. Soc., **77**, 1122 (1955).

(5) E. D. Hughes, et al., J. Chem. Soc., 1220 (1957).

(6) J. E. Leffler and E. Grunwald, "Rates and Equilibria of Organic Reactions," John Wiley and Sons, Inc., New York, N. Y., 1963, pp. 88, 89.

Fig. 2.—Concentration dependance of line broadening of methyl protons of $(p\text{-}CH_3C_6H_4)_3C^+SbCl_6^-$ (II) and $(p\text{-}CH_3C_6H_4)_3CCl$ (I) in CH_2Cl_2 solution at $-56°$. The concentration of I is: (A) 0.167 M, (B) 0.125 M, (C) 0.084 M.

$$\tau = \text{concentration of species/rate of disappearance}$$
$$\text{of species} \qquad (4)$$

Assuming bimolecular process (1), eq. 5 is derived

$$\tau_I = \frac{[Ar_3CCl]}{k_x[Ar_3CCl][Ar_3C^+Y^-]} = \frac{1}{k_x[Ar_3C^+Y^-]}$$
$$\qquad\qquad\qquad (5)$$
$$\tau_{II} = \frac{Ar_3C^+Y^-}{k_x[Ar_3C^+Y^-][Ar_3CCl]} = \frac{1}{k_x[Ar_3CCl]}$$

Lack of agreement between the line-broadening data and the concentration dependence requirements of (5) effectively eliminates this mechanism.

For the S_N1 mechanism (2), only k_f is involved in disappearance of I, yielding

$$\tau_I = [Ar_3CCl]/(k_f[Ar_3CCl]) = 1/k_f \qquad (6)$$

A simplified derivation of $\tau_{Ar_3C^+}$ is obtained from (4) if we assume that $k_{x'}[Ar_3C^+Cl^-][Ar_3C^+Y^-] >> k_r[Ar_3C^+Cl^-]$ and $[Ar_3C^+Y^-] >> [Ar_3C^+Cl^-]$.[7] The only process now responsible for carbonium ion disappearance is that whose rate is $k_r[Ar_3C^+Cl^-]$, yielding

$$\tau_{II} = [Ar_3C^+Y^-]/(k_r[Ar_3C^+Cl^-]) =$$
$$[Ar_3C^+Y^-]/(k_f[Ar_3CCl]) \qquad (7)$$

The requirements of the lifetime expressions are clear: (6) states that τ_I be concentration invariant, and (7) dictates that τ_{II} vary directly with the ratio of II:I. The experimental results (Fig. 2 and Table I) are in accord with these conclusions. Variation in concentration of I or II does not affect the chloride line whose half-width remains at 7.0 $\pm$ 0.5 c.p.s., and application of (3) and (6) yields an average value of $1/\tau_I = k_f$ of 8.9 $\pm$ 0.2 sec.$^{-1}$ at $-56°$. The calculated τ_{II} (column 4, Table I) exhibits the concentration dependance predicted by (7) and yields (column 5, Table I) an average value for k_f of 7.8 $\pm$ 0.4 sec.$^{-1}$, in good agreement with the previous value.

(7) The first assumption follows from the work of Swain,[4] and the second is justified by the small equilibrium constant for the ionization of I (see below).

TABLE I

VARIATION OF DIFFERENTIAL LINE BROADENING WITH CONCENTRATION AT $-56°$; DETERMINATION OF k_f

$[I]$, M	$[II]$, M	$1/\tau_I = k_f$, sec.$^{-1}$ [a]	$1/\tau_{II}$, sec.$^{-1}$ [a]	k_f, sec.$^{-1}$ [b]
0.125	0.125	9.1	8.1	8.1
0.167	0.084	9.1	14.7	7.4
0.084	0.167	8.8	3.7	7.4
0.063	0.063	8.8	8.1	8.1
0.083	0.042	8.8	16.1	8.2

[a] From eq. 3. [b] From eq. 7.

Knowledge of the equilibrium constant ($K_{eq} = k_f/k_r$) now makes k_r accessible. Ultraviolet data,[8] using similar solutions of I as for the n.m.r. experiments, yielded a value of $K_{eq} = 2.8 \times 10^{-4}$ at $-56°$.[9] Using an average value of $k_f = 8.4$ sec.$^{-1}$, then $k_r = 3 \times 10^4$ sec.$^{-1}$.

The conclusion that exchange between I and II occurs via an Sn1 process agrees with our preliminary observation that factors which affect the exchange rates are those which modify k_f. Accordingly, rate enhancements are observed with: (a) increasing solvent polarity, (b) increasing halogen polarizability, and (c) cation-stabilizing ring substituents. Work is continuing.

Acknowledgment.—The authors thank Professors G. Whiteside, C. G. Swain, and H. Morawetz for helpful discussions.

(8) We thank Dr. R. Waack and Miss M. Doran for the low-temperature ultraviolet data.

(9) This compares to $K_{eq} = 2.1 \times 10^{-1}$ for I in Cl_3CCHCl_2 at 20° [A. G. Evans, A. Price, and J. H. Thomas, *Trans. Faraday Soc.*, **52**, 332 (1956)].

THE DOW CHEMICAL COMPANY H. H. FREEDMAN
EASTERN RESEARCH LABORATORY A. E. YOUNG
FRAMINGHAM, MASSACHUSETTS V. R. SANDEL

The Phenylation of Pyridine–Metal Complexes

Sir:

The chemical reactions of coordinated ligands have been an area of recent interest to others,[1] and also to us in terms of their free-radical chemistry.[2] To further this inquiry, a set of experiments was designed whereby phenyl radicals were caused to react with pyridine dissolved in N,N-dimethylformamide and in separate experiments with a group of pyridine–metal complexes dissolved in the same solvent.

A large number of complexes of pyridine were prepared, and the ones indicated in Table I were found to be completely stable to the reaction conditions (all analyses were satisfactory). This stability was ascertained by using the pyridine ligand bands in the infrared.[3] The stable complexes showed no change in the ligand bands when newly dissolved in dimethylformamide, after standing at least 4 days in the dimethylformamide at 25°, and after 4 days in the solvent plus the phenyl source at 25°. However, new

(1) "Reactions of Coordinated Ligands," D. H. Busch, Ed., Advances in Chemistry Series 37, American Chemical Society, Washington, D. C., 1963.

(2) R. J. Gritter and E. L. Patmore, *Proc. Chem. Soc.*, 328 (1962).

(3) P. C. H. Mitchell, *J. Inorg. Nucl. Chem.*, **21**, 383 (1961).

TABLE I

PHENYLATION ISOMER RATIOS

Complex, mole	Phenyl source, mole	2-Phenyl, %	3-Phenyl, %	4-Phenyl, %
Pyridine[c] (0.150)	0.0150	41.1	39.0	19.8
Co(Py)₃Cl₃ (0.021)	0.0124	66.7	13.1	20.2
Cr(Py)₃Cl₃ (0.043)	0.0124	45.0	19.0	36.0
Zn(Py)₂(SCN)₂ (0.049)	0.0124	46.0	23.0	31.8
Mn(Py)₄(SCN)₂ (0.024)	0.0124	34.9	32.8	32.9
Ni(Py)₄(SCN)₂ (0.018)	0.0124	23.8	34.5	41.8
Cd(Py)₂(SCN)₂ (0.049)	0.0124	43.3	33.6	23.2

[c] Uncomplexed.

bands were formed owing to the phenylation of the complexes under the last conditions, but no bands owing to free pyridine. When the decomposition of any complex was evidenced by either a decrease in the intensity of the ligand infrared bands, or a color change, or the formation of a precipitate (silver metal by an oxidation-reduction reaction with the silver complex) over a 5-day period, that complex was discarded. The phenyl source used was N-nitroso-*sym*-diphenylurea which was completely decomposed at 25° over a 3-day period under the reaction conditions. This phenyl source was prepared by the known method[4] and also by the reaction of diphenylurea with nitrosylsulfuric acid generated *in situ* by the action of water upon nitrosylsulfuric anhydride.

The pure isomeric phenylpyridines were prepared by the phenylation of pyridine by a standard method[5] and separation of the three phenylpyridines by preparative thin layer chromatography. The picrates of the separated samples agreed with those reported previously.[5] Mixtures of the isomers, both prepared and from the reactions, could be separated and their relative amounts measured by gas chromatography using specially prepared columns. The reliability of the method for isomer determination was checked and the results are: known mixture, 39.1:39.9:21.0; gas chromatographic integration values, 41.5:36.2:22.2; column factor, 0.94:1.10:0.95; and calculated values, 38.6:38.0:23.2. It was shown that the isolation procedures were sufficiently efficient to begin with 0.48 g. of products in a 70.9:18.9:10.1 ratio and obtained 0.47 g. in a 71.0:19.6:9.5 ratio. When these methods were applied to phenylation reaction mixtures involving complexes, the data in Table I were obtained.

A typical reaction involved dissolving 16.7 g. (0.049 mole) of dipyridinezinc(II) thiocyanate in 80 ml. of dimethylformamide, followed by the rapid addition of 3.00 g. (0.124 mole) of N-nitroso-*sym*-diphenylurea and allowing the mixture to stand for 3 days. Isolation involved evaporation of the solvent under vacuum, decomposition of the complex with base, filtration, extraction with toluene, acidification, extraction, neutralization, extraction with carbon disulfide, and

(4) A. Hantzsch and E. Wechsler, *Ann.*, **325**, 226 (1902).

(5) J. W. Haworth, I. M. Heilbron, and D. H. Hey, *J. Chem. Soc.*, **348**, 372 (1940).