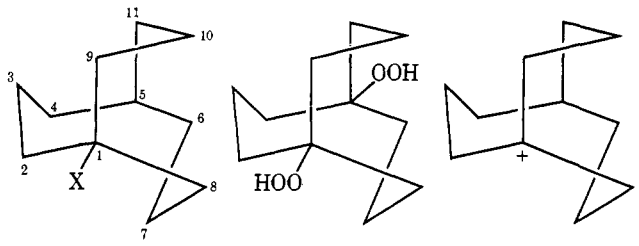
Enhancement of Reactivity at Bridgehead Positions

Sir:

The pioneering work of Bartlett and Knox[1] established that carbenium ion reactions at the bridgehead positions of some of the smaller bridged ring systems (*e.g.*, 1-norbornyl) were strongly inhibited.[2] Although subsequent investigations have shown that a wide range of bridgehead reactivities are possible, almost all such systems studied to date are less reactive than typical acyclic analogs.[2,3] We now report that rate enhancements of large magnitude are also possible in bridgehead systems.

Unusually high bridgehead reactivity of bicyclo[3.3.3]undecane (manxane, I-H)[4] in processes involving $sp^3 \rightarrow sp^2$ rehybridization is suggested by the synthesis of the mono-(I-OOH) or dihydroperoxides (II) by simply bubbling air through a solution of I-H in pentane.[5]



I II III

Empirical force field (strain) calculations[6] afford a reasonably accurate method of predicting bridgehead reactivities.[3,7] Such calculations of the 1-manxyl system[3] indicate that 6.8 kcal strain should be *relieved* in going from the parent hydrocarbon (I-H) to the 1-cation (III). When this value is substituted into the linear free energy relationship (eq 1),[3] a solvolytic

$$-\log k \text{ (chlorides, 80\% EtOH, 70°)} = (0.32)\Delta H(\text{calcd}) + 2.15 \quad (1)$$

rate constant of $k \sim 1.1$ sec^{-1} is predicted for 1-manxyl chloride (I-Cl). In other words, III should be one of the most reactive nonresonance stabilized tertiary halides![8]

Manxane[4] was converted to its 1-hydroxy derivative (I-OH),[9] mp 210–211° (sealed tube), either by $LiAlH_4$ reduction of I-OOH or by treatment of manxane with *t*-BuOCl and aqueous work-up. Treatment of 1-manxanol (I-OH) with thionyl chloride in pentane at 0° gives the corresponding chloride (I-Cl) as a waxy solid.[9] The solvolysis of I-Cl was followed conductometrically at 5° intervals using a special apparatus which facilitates the study of highly reactive substrates.[10] In 80% aqueous acetone, I-Cl gave $k = 4.71 \times 10^{-2}$ sec^{-1} at 20.3° with $\Delta H^{\ddagger} = 16.2$ kcal/mol and $\Delta S^{\ddagger} = -9.6$ eu, while in 80% aqueous ethanol $k(20.2°) = 2.57 \times 10^{-1}$ with $\Delta H^{\ddagger} = 16.0$ kcal/mol and $\Delta S^{\ddagger} = 5.5$ eu. 1-Manxyl chloride (I-Cl) is *ca.* 10^4 more reactive than *tert*-butyl chloride in the same solvents.[11] The extrapolated rate constant for I-Cl at 70° and 80% ethanol is 17.4 sec^{-1}, even faster than that predicted by eq 1. Although the linear free energy relationship of eq 1, including the new data for 1-manxyl chloride, gives a reasonable fit (correlation coefficient = 0.941) for bridgehead chlorides spanning a reactivity range of 10^{10}, recalculation of the correlation line by least-squares treatment results in eq 2 and the correlation coefficient

$$-\log k(\text{chloride, 80\% EtOH, 70°}) = (0.35)\Delta H(\text{calcd}) + 1.90 \quad (2)$$

improves to 0.960.

The strain calculations, summarized in Table I, suggest that the rate enhancement of I-Cl is due largely to the relief of angle strain during ionization. This is not surprising, since all of the CCC bond angles in manxane are considerably larger than the ideal tetra-

Table I. Calculated Strain Energies, kcal/mol[a]

Strain component	Manxane (I-H)	1-Manxyl cation (III)	ΔH (calcd)
Bond stretching	1.14	1.37	+0.23
Angle strain	12.47	8.16	−4.31
Torsional strain	8.75	7.20	−1.55
Nonbonded strain	4.66	3.42	−1.24
Total strain	26.92[b]	20.15	−6.77

[a] Bingham force field (ref 3). A newer force field (ref 7) gives somewhat different results, with only changes in angle and nonbonded strains being significant. [b] Other force fields give similar values (see ref 6).

(1) P. D. Bartlett and L. H. Knox, *J. Amer. Chem. Soc.*, **61**, 3184 (1939).

(2) For reviews see R. C. Fort, Jr., in "Carbonium Ions," Vol. IV, G. A. Olah and P. v. R. Schleyer, Eds., Interscience, New York, N. Y., 1973, Chapter 32, and references cited therein.

(3) (a) R. C. Bingham and P. v. R. Schleyer, *J. Amer. Chem. Soc.*, **93**, 3189 (1971); (b) R. C. Fort, Jr., R. E. Hornish, and G. A. Liang, *ibid.*, **92**, 7558 (1970).

(4) (a) M. Doyle, W. Parker, P. A. Gunn, J. Martin, and D. D. MacNicol, *Tetrahedron Lett.*, 3619 (1970); (b) J. C. Coll, D. R. Crist, M. C. G. Barrio, and N. J. Leonard, *J. Amer. Chem. Soc.*, **94**, 7092 (1972); (c) A. H. J. Wang, R. J. Missavage, S. R. Byrn, and I. C. Paul, *J. Amer. Chem. Soc.*, **94**, 7100 (1972).

(5) A referee has pointed out that this observation does not really indicate special reactivity, for example, decalin, derivatives of which react only two–three times faster than *tert*-butyl in C^+ processes, also can be converted to the hydroperoxide by a similar process (R. C. Fort and P. v. R. Schleyer, *Advan. Alicyclic Chem.*, **1**, 283 (1966)). We observe that qualitatively the reaction of manxane with atmospheric oxygen is extremely rapid relative to bicyclo[3.3.2]decane which, in turn, is more reactive than bicyclo-[3.3.1]nonane. In addition in ref 3, attention has been drawn to a correlation between bridgehead radical reactivity, cationic reactivity, and calculated strain energy differences.

(6) E. M. Engler, J. D. Andose, and P. v. R. Schleyer, *J. Amer. Chem. Soc.*, **95**, 8005 (1973), and literature cited therein.

(7) J. L. Fry, E. M. Engler, and P. v. R. Schleyer, *J. Amer. Chem. Soc.*, **94**, 4628 (1972). The force field in this paper has been modified from that in ref 3, but, in general, the reactivity predictions are similar with both force fields. See Table III for comparisons.

(8) For other highly reactive tertiary halides, see, *e.g.*, P. D. Bartlett and M. S. Swain, *J. Amer. Chem. Soc.*, **77**, 2801 (1955); V. J. Shiner, Jr., and G. F. Meier, *J. Org. Chem.*, **31**, 137 (1966); and ref 3.

(9) The ir, ^{1}H nmr, and Eu(dpm)$_3$-shifted spectra and ^{13}C nmr spectrum were all consistent with the structure I–OH. The corresponding high resolution mass spectrum showed a small molecular ion at 168 ($C_{11}H_{20}O$) and accurate mass measurement of the $(M - H_2O)^+$ gave *m/e* 150.1410 (calculated for $C_{11}H_{18}$, 150.1409). The ir and ^{1}H nmr spectra of I-Cl were consistent with the assigned structure, and on short exposure to atmospheric moisture the chloride is totally converted to I–OH. The high resolution mass spectrum of I-Cl showed no parent ion but the $(M - Cl)^+$ gave an accurate mass of 151.1482 (calculated for $C_{11}H_{19}$, 151.1487).

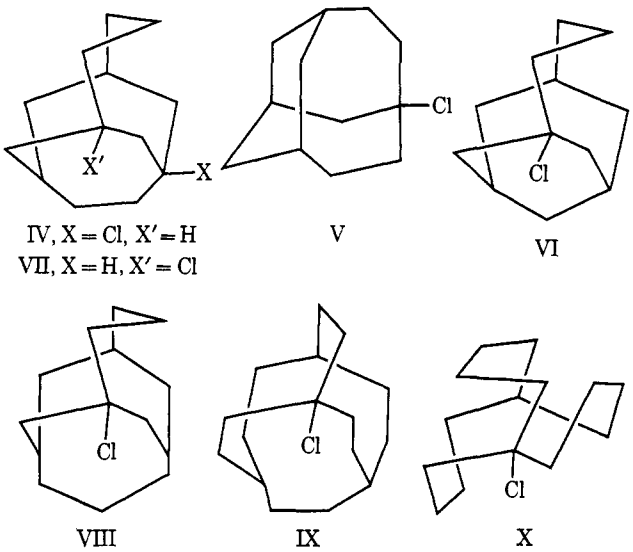
(10) A. C. Knipe, D. McLean, and R. L. Tranter, *J. Sci. Instrum.*, 7, 586 (1974).

(11) H. C. Brown and H. A. Berneis, *J. Amer. Chem. Soc.*, **75**, 10 (1953); G. R. Cowie, H. J. M. Fitches, and Kohnstam, *J. Chem. Soc.*, 1585 (1963).

Table II. Predicted Rate Constants for Reactive Bridgehead Systems

Compounds	Bingham force field[a] ΔH(calcd),[c] kcal/mol	Bingham force field[a] k(calcd),[d] sec^{-1} 70°, 80% EtOH	Engler force field[b] ΔH(calcd),[e] kcal/mol	Engler force field[b] k(calcd), sec^{-1} [f] 70°, 80% EtOH
1-Tricyclo[5.4.1.1^{3,9}]tridecyl chloride (IV)	−3.75	2.6×10^{-1}	−3.64	4.5×10^{-2}
6-Tricyclo[4.4.1.1^{3,9}]dodecyl chloride (V)[g]	−3.87	2.8×10^{-1}	−4.73	1.5×10^{-1}
3-Tricyclo[5.3.1.1^{3,9}]dodecyl chloride (VI)[h]	−4.35	4.2×10^{-1}	−6.13	3.7×10^{-1}
1-Bicyclo[3.3.3]undecyl chloride (I, X = Cl)	−6.77	2.9	−8.36	2.5
3-Tricyclo[5.4.1.1^{3,9}]tridecyl chloride (VII)	−7.35	4.7	−8.32	2.5
1-Tricyclo[5.5.1.1^{3,9}]tetradecyl chloride (VIII)	−8.05	8.3	−10.43	15.
1-Tricyclo[5.5.2.2^{4,10}]tetradecyl chloride (IX)[i]			−17.38	5.4×10^{3}
1-Bicyclo[4.4.4]tetradecyl chloride (X)	−14.94	2.0×10^{3}	−20.80	1.2×10^{5}

[a] See ref 3. [b] See ref 7. [c] Difference of strain energy between carbenium ion and corresponding hydrocarbon. [d] Calculated from eq 2. [e] Difference of steric energy between carbenium ion and corresponding hydrocarbon. [f] Calculated from $-\log k$(chlorides, 80% EtOH, 70°) = $(0.37)\Delta H + 2.70$, based on the treatment given in ref 6. [g] 1,3-Bishomoadamant-6-yl chloride. [h] 1,1-Bishomoadamant-3-yl chloride. [i] Hexahomoadamant-1-yl chloride.



hedral value[12] and an sp^2 hybridized carbon is more readily accommodated at the bridgehead. Flattening at the bridgehead also reduces the repulsive nonbonded interactions involving the C-3, C-7, and C-10 methylene groups. A similar, but smaller, solvolytic rate enhancement is exhibited by monocyclic cyclooctyl derivatives.[13] Since the three faces of I-Cl consist of chair–boat cyclooctane rings, the rate enhancement observed for I-Cl can be considered to be another manifestation of the "middle ring effect."[13]

The success of our calculations in predicting bridgehead reactivities[3,7] has led us to search for other reactive bridgehead systems by computation. All of the polycyclic systems listed in Table II are predicted by both force field treatments[3,7] to be significantly more reactive than *tert*-butyl chloride. It has been observed recently[14] that both 1,1-bishomoadamantane (VI-H) and 1,3-bishomoadamantane (V-H), like manxane (I-H), are not stable in air and form hydroperoxides. 1-Chlorobicyclo[4.4.4]tetradecane (X), expected to be even more reactive than I-Cl, would appear to be an excellent objective for experimental investigation.

(12) Engler's force field[6] gives the following bond angles for manxane: $\angle C_2C_1C_8$, 115.2°; $\angle C_1C_2C_3$, 118.8°; $\angle C_2C_3C_4$, 118.2°. Similar values have been found experimentally for 1-azamanxane.[4c]

(13) See A. Streitwieser, Jr., "Solvolytic Displacement Reactions," McGraw-Hill, New York, N. Y., 1962, p 95; J. Sicher, *Progr. Stereochem.*, **3**, 202 (1962); H. C. Brown and K. Ichikawa, *Tetrahedron*, **1**, 221 (1957).

(14) Professor T. Sasaki, private communication.

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William Parker,* Roy L. Tranter, C. Ian F. Watt
Chemistry Department, University of Stirling
Stirling, Scotland

Laurence W. K. Chang, Paul v. R. Schleyer
Department of Chemistry, Princeton University
Princeton, New Jersey 08540

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Sign Changes in the ^{15}N–^{31}P Directly Bonded Coupling Constant

Sir:

The measurement of directly bonded nmr coupling constants is an important experimental activity in regard to the development of bonding theory.[1] Relative sign data pertaining to the group V and group VI nuclei are particularly significant because it is here that sign changes may occur.[1,2] Both theoretical and experimental considerations[1,2] indicate that the couplings involving the ^{31}P nucleus are predominantly dependent[3] upon the phosphorus coordination number, hence it seemed important to determine the signs and magnitudes of the ^{15}N–^{31}P coupling constants in the pentacoordinate compound $F_3P(^{15}NH_2)_2$, **1**,[4] and the tricoordinate–tetracoordinate molecule, $F_3P{=}^{15}NP'F_2'$, **2**,[4] and to compare them with that in the tricoordi-

(1) (a) J. A. Pople and D. P. Santry, *Mol. Phys.*, **8**, 1 (1964); (b) W. McFarlane, *Quart. Rev., Chem. Soc.*, **23**, 187 (1969); (c) C. J. Jameson and H. S. Gutowsky, *J. Chem. Phys.*, **51**, 2790 (1969).

(2) C. J. Jameson, *J. Amer. Chem. Soc.*, **91**, 6232 (1969).

(3) Other factors can be important in, *e.g.*, heterocyclic phosphines. See, *e.g.*, D. Gagnaire, J. B. Robert, and J. Verrier, *Chem. Commun.*, 819 (1967); G. A. Gray and S. E. Cremer, *J. Chem. Soc., Chem. Commun.*, 451 (1974).

(4) These compounds were synthesized by replacing ammonia with 96.5% ^{15}N enriched ammonia in the literature preparations. For **1** see M. Lustig and H. W. Roesky, *Inorg. Chem.*, **9**, 1289 (1970); for **2** see G. E. Graves, D. W. McKennon, and M. Lustig, *ibid.*, **10**, 2083 (1971).