mg. of deep-orange needles, m.p. 204–206° (capillary, inserted at 175°). From the mother liquor, an additional 12.6 mg., m.p. 203–205° was obtained. The analytical sample was obtained from the first crop.

Anal. Calcd. for $C_{20}H_{28}N_2O$, $C_6H_3N_3O_7$: C, 57.66; H, 5.77; N, 12.93. Found: C, 57.81; H, 5.71; N, 13.08.

The picrate, 35 mg., was converted to the free base by passing its chloroform solution over alumina (5 g., act. I, neutral). The eluate was concentrated and the residue distilled (0.05 mm., 180° air-bath). The colorless glass obtained could not be induced to crystallize. It is characterized by its ultraviolet spectrum in ethanol (λ_{max} 228, 278, 291(sh) mμ; ϵ 43,600, 8,020, 5,680; λ_{min} 252 mμ, ϵ 4,300), optical rotatory power ($[\alpha]^{25}$D $-103°$, *c* 0.102 in dioxane) and mass spectrum (Fig. 2b), which also permits the determination of the molecular weight of 312.

Fractions 23–30 (eluted with benzene) contained, according to their mass spectra, mainly a compound of molecular weight 342 (a dimethoxyquebrachamine) and were combined (47 mg.) and converted to the picrate. The orange needles obtained on recrystallization from methanol melted under decomposition at 224–228°.

Anal. Calcd. for $C_{21}H_{30}N_2O_2$, $C_6H_3N_3O_7$: C, 56.73; H, 5.82: Found: C, 56.49; H, 5.77.

Fractions 45–47 (22 mg., eluted with benzene–chloroform 10:2) were shown by their mass spectra to consist mainly of deacetylaspidospermine (IIIb). Fractions 48–56 (76 mg., same solvent) contained IIIb and a compound of molecular weight 342, according to its mass spectrum a methoxydeacetylaspidospermine.

Isolation of Va and Vb.—The crude mixture (70 mg.) obtained on oxidation of IIIb was acetylated to facilitate the separation of compound 310 from the unchanged starting material and other by-products. After addition of 3 ml. of acetic anhydride and standing overnight the mixture was poured into 50 ml. of 2.5 *N* NaOH and after standing for 5 min. was extracted three times with ether. The ether phases were washed with water, dried over potassium carbonate and the solvent removed. A sample of the residue, 61 mg. of a brownish oil, was separated by gas chromatography (8% Apiezon L, 260°) permitting the isolation of a pure sample of Va, the mass spectrum of which is shown in Fig. 3b. The ultraviolet spectrum showed λ_{max} 228, 236(sh), 255, 307 mμ; ϵ 16,500, 13,700, 4,900 and 4,500; λ_{min} 246, 283; ϵ 4,700, 3,320.

Sodium Borodeuteride Reduction of Crude Va.—The product (94 mg.) of oxidation of 100 mg. of deacetylspidospermine obtained in an experiment similar to the one described above was reduced with 20 mg. of sodium borodeuteride[29] in 2 ml. of water as described earlier. The crude product, 54 mg., was separated by gas chromatography and the methoxyquebrachamine fraction collected. The mass spectrum (Fig. 4) shows the incorporation of one atom of deuterium.

Lithium Aluminum Deuteride Reduction of Crude Va.—The product (32 mg.) of another oxidation of IIIb was dissolved in 5 ml. of tetrahydrofuran and transferred to an ampoule. A large excess of lithium aluminum deuteride was added and the sealed ampoule held at 70° for 1 hr. After cooling, the ampoule was opened, 1 ml. of water and some ether added, shaken vigorously, centrifuged and the ethereal solution decanted. The extraction was repeated three times, the ether phases washed, dried and evaporated. The residue (24 mg.) was separated by gas chromatography and the deacetylaspidospermine fraction collected for a mass spectrum.

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[29] The authors are indebted to Prof. R. E. Davis for a gift of sodium borodeuteride.

COMMUNICATIONS TO THE EDITOR

EFFECT OF BOND ENERGY ON REACTIONS OF HOT HYDROGEN ATOMS AT C-H BONDS

Sir:

In a recent letter[1] Root and Rowland have presented a new and significant result on the reaction of hot tritium atoms as produced by nuclear recoil. They investigated hot hydrogen substitution

$$T + RH \longrightarrow RT + H \qquad (1)$$

in mixtures of methane and *n*-butane. It was found that the total probability of this process, per C–H bond, is about the same in the two molecules. On this basis they suggested that steric obstruction is not a significant controlling factor in such reactions. Steric obstruction previously had been suggested[2] as possibly being responsible for observed variations in the yield ratio of substitution (1) relative to abstraction (2)

$$T + RH \longrightarrow HT + R \qquad (2)$$

reactions in various alkanes. Root and Rowland postulate that these variations are caused instead by a sensitive dependence of hot abstraction (but not substitution) on C–H bond energy. This proposal is particularly interesting since in prior work there has been little indication that true hot reactions resemble thermal processes in being extremely sensitive to bond energy.[3] Furthermore, while there must obviously be some effect of bond energy on such hot processes it is most difficult to conceive of a physical basis for as great a dependence as is postulated (see ref. 4).

In this letter we wish to: (1) Present certain experimental data indicating that the effect of the energy of the C–H bond is unlikely to be of sufficient magnitude to be consistent with Root and Rowland's proposal. (2) Point out that Root

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[1] J. W. Root and F. S. Rowland, *J. Am. Chem. Soc.*, **84**, 3027 (1962).

[2] D. Urch and R. Wolfgang, *ibid.*, **83**, 2982 (1961).

[3] Certain hot addition reactions result in an intermediate which subsequently de-excites by bond rupture [D. Urch and R. Wolfgang, *ibid.*, **81**, 2025 (1959)]. Such secondary consequences of primary hot reactions will be sensitive to bond energy.

[4] There will, of course, be some effect of a smaller bond energy on reaction probability. The most obvious is that it might extend downward the minimum or threshold energy for reaction. The magnitude of this effect can be estimated using the kinetic theory of hot reactions (P. J. Estrup and R. Wolfgang, *ibid.*, **82**, 2665 (1960)). If reaction occurs with probability $p(E)$ on collision in the energy interval E_0 to ∞ then the total probability of hot reaction is

$$P = 1 - \exp\left(-\frac{f}{\alpha}\int_{E_0}^{\infty}\frac{p(E)}{E}\,dE\right)$$

where f is the probability of collision with a reagent molecule and α the average logarithmic energy loss per collision. If the C–H bond energy is lowered by ΔE, one way of estimating the effect of this would simply be to replace $p(E)$ by $p(E + \Delta E)$ in this equation. However, the shape of the function $p(E)$ is not known. It may be roughly approximated by assuming a constant value between the energy limits E_1 and E_2. In this case the effect of lowering the bond energy might be to drop the lower limit to $E_1 - \Delta E$. Following this procedure, using reasonable values of the parameters involved, and assigning the entire increase in reaction probability to abstraction, it is difficult to see how this effect of bond energy could conceivably reach a magnitude to be consistent with Root and Rowland's proposal.

TABLE I

YIELDS OF VARIOUS REACTIONS IN CH_3F AND CD_3F RELATIVE TO F SUBSTITUTION[a]

Reaction	Product	CH_3F	CD_3F
H(D) Abstraction	HT or DT	585 ± 4	636 ± 5
H(D) Substitution	CH_2TF or CD_2TF	297 ± 1	309 ± 1
F Substitution	CH_3T or CD_3T	100	100
Ratio: $\frac{\text{H Abstraction}}{\text{H Substitution}}$		1.97 ± 0.01	2.06 ± 0.01

[a] Yields determined in usual manner using 1 atmosphere CH_3F or CD_3F, ~1 cm. He^3 as source of T, I_2 as scavenger and customary neutron irradiation and analysis procedures.[2] Errors are standard deviations of the mean of six or seven replicate runs. Absolute total yield of all measured hot products is 22 ± 3% higher in CH_3F than in CD_3F.

and Rowland's discovery admits of another explanation which is independent of any effect of bond strength.

In support of the postulated bond energy effect Root and Rowland cite earlier results[5] on isotope effects on the hot abstraction reaction in CH_2D_2 and mixtures of CH_4 and CD_4. These show a decrease in deuterium abstraction relative to protium abstraction of the order of 30%. If this isotope effect is attributed to the difference in energy of the C–H and C–D bonds (~0.9 kcal.) and if the substitution reaction (1) is relatively unaffected, an energy dependence of the abstraction/substitution ratio sufficient to account for the butane–methane data would be indicated.

However, other earlier data[6] on CH_4 and CD_4, seem to indicate an isotope effect on the substitution reaction (2) similar to that on abstraction (1). This has now been confirmed by high precision measurements[7] on protonated and deuterated methyl fluoride. It appears that the efficiencies of all reactions of hot hydrogen are lower by about the same magnitude in the deuterated system.

Table I shows the probability of hydrogen abstraction and substitution relative to fluorine substitution. It is evident that the isotope effect on the ratio of abstraction to substitution is too small by an order of magnitude,[8] and has the wrong sign to be caused by a bond energy dependence of the nature postulated by Root and Rowland.

The actual cause of the isotope effects observed cannot be discussed here. However, without invoking fortuitous cancellations of large isotope effects of different and obscure origins it is difficult to reconcile these data with Root and Rowland's proposal.

In discussing the relation of their data to the postulated steric effect,[2] Root and Rowland used the approximate empirical equation[2] relating abstraction (to form HT) to substitution (to form RT)

$$\frac{HT}{RT} = \frac{\Sigma n_i}{\Sigma n_i\,(1 - \Omega)^i}$$

n_i is the number of primary, secondary and tertiary H atoms, i = 1, 2 or 3, respectively, and Ω is a fitted quantity which may be interpreted as an obstruction parameter. On applying this equation to predict the relative amount of displacement in two different molecules (CH_4 and n-butane), and finding it inadequate, the conclusion was drawn that[1] "the steric obstruction implied in the formula is clearly not the dominant factor affecting these substitutions, and is probably of minor importance." The equation was, however, explicitly developed to predict an intramolecular ratio.[2] To apply it to an intermolecular comparison necessitates further assumptions regarding the relative reaction cross-sections and reaction energy ranges of the two molecules. Thus Root and Rowland assumed that the probability of abstraction per collision corresponds simply to the number of C–H bonds in the molecule struck. It was also implicitly assumed that the energy dependence for such reaction of recoil tritium was similar for methane and n-butane.

We feel there is no *a priori* basis for such assumptions.[9] In fact Root and Rowland's result could be expressed by simply stating that the ratio of total reaction cross-sections of n-butane and methane, appropriately integrated over all energies, is significantly larger than the ratio of geometric collision cross-sections. Given this enhanced total probability of reaction with n-butane, the above equation is consistent with the observed[2] ratios of abstraction to displacement.

While Root and Rowland's discovery is most suggestive, it is therefore not sufficient as a basis for a definite decision regarding the existence and magnitude of the postulated steric effect. This hypothesis must continue to be treated as an open question until there is direct evidence on the intramolecular distribution of tritium in a gas phase molecule.

The question remains of what does cause the low reaction efficiency of methane relative to butane. It seems quite likely that the final explanation will involve the difference in complexity of these systems. A molecule as simple as methane is likely to be a poor sink for the excess energy and momentum that will normally have to be carried away by the products of a hot reaction. This will tend to restrict the range of energy and other collision parameters for which reactive collision leading to molecular products is possible.

Acknowledgments.—This work was supported by the U. S. Atomic Energy Commission. The author is obliged to Mr. H. Clement Jurgeleit for permitting the use of his data prior to its full publication.[7] We wish to thank Professors F. S.

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(5) J. K. Lee, B. Musgrave and F. S. Rowland, *J. Phys. Chem.*, **64**, 1959 (1960).

(6) R. J. Cross and R. Wolfgang, *J. Chem. Phys.*, **35**, 2002 (1961).

(7) H. C. Jurgeleit and R. Wolfgang, in preparation for publication.

(8) To account for the observed[2] variations in abstraction to displacement a bond energy effect of 18–35% per kcal. would be required. The C–H and C–D bonds differ by 0.9 kcal. (bond energies from S. W. Benson, "Foundations of Chemical Kinetics," McGraw-Hill Book Co., New York, N. Y., 1960, p. 676).

(9) Available data indicate these assumptions are unjustified for 2 ev. hot hydrogen atoms (Carter, Hamill and Williams, *J. Am. Chem. Soc.*, **77**, 6457 (1955).

Rowland, Colin MacKay and Michael Henchman for stimulating and helpful discussions.

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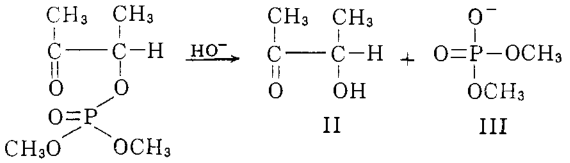
KINETICS AND MECHANISMS OF THE RAPID ALKALINE HYDROLYSIS OF DIMETHYL PHOSPHOACETOIN[1]

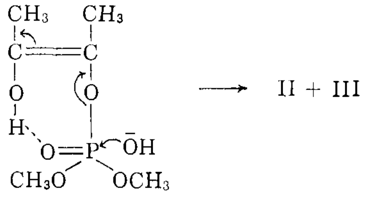
Sir:

The hydrolysis of dimethyl phosphoacetoin[2] (I) in the pH-range 7.7–8.3 gives acetoin (II) and dimethylhydrogen phosphate (III), identified as its barium salt. The reaction is first order with respect to the phosphotriester, I, and first order with respect to hydroxide ion. The second-order rate constant in this pH-range is $k_2 = 360 \pm 20$ liters-mole^{-1}-sec.$^{-1}$ at 25°. The rate was determined in 0.07 M $KClO_4$ by titration with 0.02 M NaOH in the pH-stat[3] already described. The initial concentration was 4×10^{-4} M.

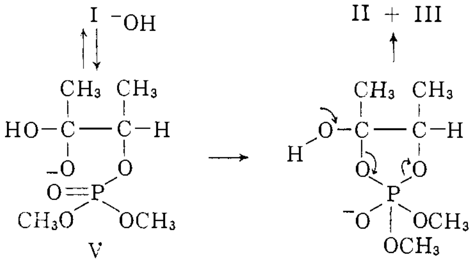

I II III

Measurements of the rate of hydrolysis of a 0.05 M solution of trimethyl phosphate in 0.02 M $KClO_4$ with 0.05 M NaOH gave 1.4×10^{-4} liters-mole^{-1}-sec.$^{-1}$ at 25°. The hydroxide ion-catalyzed hydrolysis of the simple α-ketol phosphotriester, I, is at least 2×10^6 times faster than that of trimethyl phosphate.

This enormous acceleration could be explained in two ways: (1) A substitution at phosphorus on the enediol-phosphate, IV, in which the rate enhancement would be due to the unsaturated nature of the leaving group and to hydrogen-bonding assistance. This picture is being considered further. (2) Carbonyl participation, (V), and oxyphosphorane formation, (VI), in the hydrolysis.

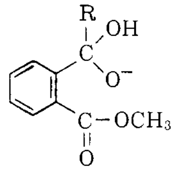

IV

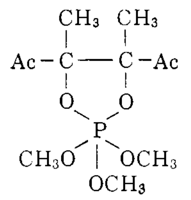
Newman and Hishida[4] have suggested that the increased rate of alkaline hydrolysis of certain methyl o-benzoylbenzoates is a consequence of steric factors which promote a mechanism involving attack of hydroxide ion on the ketonic carbonyl (VII, R = C_6H_5) followed by an intramolecular expulsion of a methoxide ion. Subsequently,

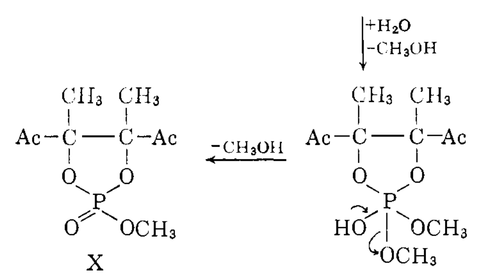

V VI

Bender and Silver[5] explained the fast rate of the hydroxide ion-catalyzed hydrolysis of methyl o-formylbenzoate in terms of aldehyde participation (VII, R = H).

We have interpreted the extremely rapid hydrolysis of the crystalline cyclic saturated oxyphosphorane,[6a] VIII, to the cyclic phosphotriester, X, in benzene or ether solution, as involving the oxyphosphorane intermediate,[6b] IX.


VII, R = C_6H_5 or H


VIII, Ac = CH_3CO



X IX

Formulas VI and IX bring out the structural features which could account for the difference in the direction of the hydrolytic cleavage of the ketol phosphate (I) and of the oxyphosphorane (VIII). In the former, the ring is not preserved due to facile C–O bond fission.

These observations may have a bearing on the chemistry of naturally occurring α-ketol phosphomonoesters such as certain sugar phosphates, and, as pointed out by Bender[5] for carboxylic esters, on enzymic processes of phosphate esters in general.

NOTE ADDED IN PROOF.—C. A. Vernon gives $k_2 = 1.3 \times 10^{-4}$ liters-mole^{-1}-sec.$^{-1}$ at 25° for the alkaline hydrolysis of trimethyl phosphate in water; *cf.* "Phosphoric Esters and Related Compounds," The Chemical Society, London, Special Publication No. 8, 1957, p. 30.

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[1] These investigations are being supported by the Cancer Institute of the National Institutes of Health (CY-4769) and the Petroleum Research Fund Administered by the American Chemical Society.

[2] F. Ramirez and N. B. Desai, *J. Am. Chem. Soc.*, **82**, 2652 (1960).

[3] L. Larsson and B. Hansen, *Svensk Kem. Tidskr.*, **68**, 521 (1956).

[4] M. S. Newman and S. Hishida, *J. Am. Chem. Soc.*, **84**, 3582 (1962).

[5] M. L. Bender and M. S. Silver, *ibid.*, **84**, 4589 (1962).

[6] (a) F. Ramirez, N. Ramanathan and N. B. Desai, *ibid.*, **84**, 1317 (1962); (b) in press.

[7] Alfred P. Sloan Fellow 1961–1962. The authors appreciate the opportunity of examining the manuscripts of Newman and Hishida[4] and of Bender and Silver[5] before publication.

[8] A B Pharmacia, Uppsala, Sweden.