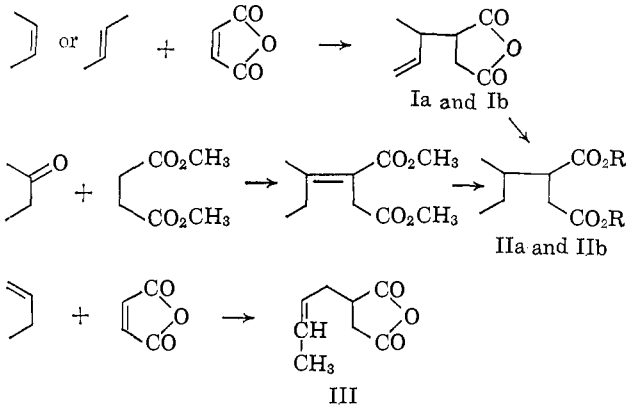
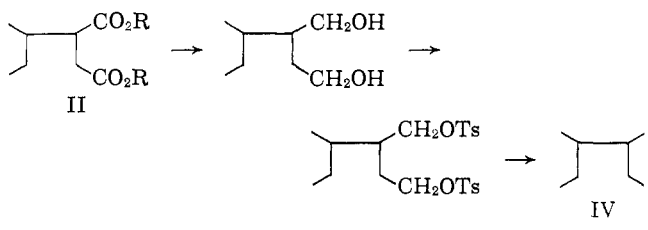
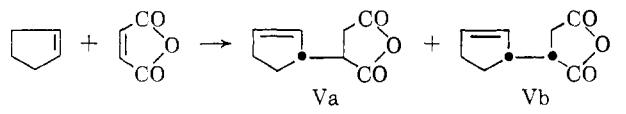


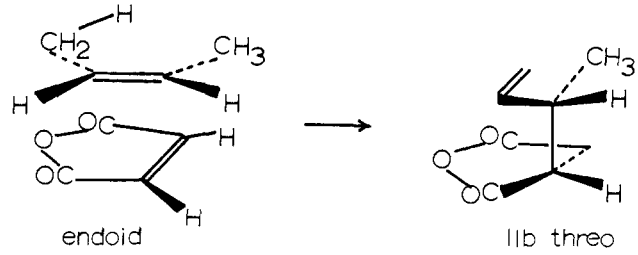
(II, R = H), gives a diastereomerically pure acid IIa (R = H), convertible with diazomethane to pure IIa (R = CH_3), which is identical with the ester corresponding stereochemically to the major component of the *trans*-2-butene–maleic anhydride adduct. Ester IIa (R = CH_3) is shown to have the *erythro* configuration by the following procedure. Partial resolution of IIa (R = H) *via* the cinchonidine salt and conversion to methyl ester give IIa (R = CH_3), $[\alpha]_D$ +13.3°. A portion of the optically active sample of IIa (R = CH_3) is made structurally symmetrical by a sequence involving lithium aluminum hydride reduction, conversion to a di-*p*-toluenesulfonate, and further lithium aluminum hydride reduction, from which is obtained *optically inactive* 3,4-dimethylhexane (IV). The optical inactivity of this hydrocarbon sample is a consequence of *meso* stereochemistry, since *optically active* 3,4-dimethylhexane (IV) is obtained by a sequence in which the remainder of the above diastereomerically pure *erythro* optically active ester IIa (R = CH_3) is first epimerized to an *erythro–threo* (IIa–IIb) mixture with sodium methoxide and then subjected to the same symmetrization sequence. Thus, the major product from *trans*-2-butene is *erythro* and that from *cis* is *threo*.



Similarly, the major isomer of the cyclopentene–maleic anhydride adduct mixture,[6] which is formed in a 3.5:1 predominance in the ene synthesis, is shown to have the *erythro* configuration Va by symmetrization of an optically active derivative to give *meso*-methyl 1,3,4,6-hexanetetracarboxylate.



On the likely but unproven assumption that carbon–carbon and carbon–hydrogen bond formation in the ene synthesis is concerted,[7] the results in the three examples reported here indicate a preference for endoid addition, which is illustrated below for the case of *cis*-2-butene. This orientation is the one favored on



simple steric grounds for the assumed concerted mechanism, in accord with the proposal of steric control made by Hill and Rabinovitz.[9] However, some electronic influence of the type that favors *endo* Diels–Alder addition cannot be excluded.[10] Furthermore, because of logical circularity, neither the present nor the previous[9] stereochemical result can be interpreted as *requiring* the concerted mechanism. Perhaps the strongest evidence against a stepwise diradical mechanism (carbon–carbon bond formation followed by intramolecular hydrogen transfer) is the apparent absence of cyclo adducts in the ene syntheses or of ene adducts in those cyclo additions[11] which clearly proceed *via* diradicals.

(6) K. Alder, F. Pascher, and A. Schmitz, *Ber.*, 76, 27 (1943).

(7) The evidence frequently cited in support of this consists of obligatory double bond movement (only one of two allylic isomers formed)[8a] and preservation of asymmetry in the product of ene syntheses with optically active olefins of the type $R_1R_2CHCH{=}CH_2$.[9] These are necessary but insufficient conditions, since a stepwise mechanism in which the carbon–carbon bond is formed *first* is also compatible with them.[8b]

(8) (a) R. T. Arnold and J. F. Dowdall, *J. Am. Chem. Soc.*, 70, 2590 (1948); (b) Arnold and Dowdall[8a] recognized the possibility of a stepwise mechanism *via* a zwitterionic intermediate. A diradical intermediate is also conceivable.

(9) R. K. Hill and M. Rabinovitz, *ibid.*, 86, 965 (1964).

(10) The orbital symmetry relationships that rationalize the Diels–Alder case [see R. Hoffmann and R. B. Woodward, *ibid.*, 87, 4388 (1965)] are also applicable to the ene synthesis. By personal communication these authors inform us that endoid addition should be the more favorable process on orbital symmetry grounds but that the preference should be smaller than in Diels–Alder reactions.

(11) P. D. Bartlett, L. K. Montgomery, and B. Seidel, *ibid.*, 86, 616 (1964), and subsequent papers.

(12) National Science Foundation Cooperative Fellow, 1963; National Institutes of Health Predoctoral Fellow, 1964–1965.

(13) National Institutes of Health Postdoctoral Fellow, 1964–1965.

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Participation of a Neighboring Ketonic Carbonyl Group in Phosphonate Ester Hydrolysis

Sir:

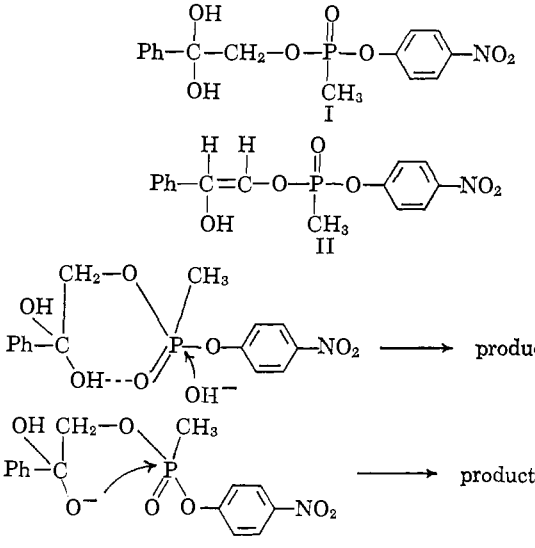
The carboxylate ion, imidazole, carboxylic acid, carboxamide, aromatic and aliphatic hydroxyl groups, and the carbonyl group can participate as intramolecular catalysts in the hydrolysis of carboxylic esters.[1] Similarly, a variety of neighboring groups can participate in the hydrolysis of phosphates.[2] These reactions may

(1) (a) M. L. Bender, *Chem. Rev.*, 60, 53 (1960); (b) B. Capon, *Quart. Rev.* (London), 18, 45 (1964); (c) Y. Shalitin and S. A. Bernhard, *J. Am. Chem. Soc.*, 86, 2291 (1964); (d) *ibid.*, 86, 2292 (1964).

(2) J. R. Cox, Jr., and O. B. Ramsay, *Chem. Rev.*, 64, 317 (1964).

serve as models of the reactions which occur at the active sites of enzymes. We report the marked enhancement of the solvolytic displacement of *p*-nitrophenol from a phosphonate ester by a neighboring ketonic carbonyl group. *p*-Nitrophenyl phenacyl methylphosphonate[3] is hydrolyzed with $k_{OH^-} = 5.106 \times 10^3\ M^{-1}\ sec^{-1}$ in 5% aqueous dioxane, 25°, over the pH range 7.2–8.0 in the presence of 0.1 *M* tris(hydroxymethyl)aminomethane (TRIS), and at pH 7.22 at constant ionic strength in TRIS buffer over the concentration range 0.1 to 0.04 *M*.[4] The reaction is first order in phosphonate, hydroxide ion, and in TRIS·base. The results are consistent with the rate expression $k_{obsd} = k_1[OH^-] + k_2[TRIS\cdot base] + k_3$, where $k_2 = 0.412\ M^{-1}\ sec^{-1}$ and $k_3 = 1.4 \times 10^{-4}\ sec^{-1}$. At pH 7.81, $t_{1/2} = 41.0$ sec for the hydrolysis of *p*-nitrophenyl phenacyl methylphosphonate. Under these conditions ethyl *p*-nitrophenyl methylphosphonate hydrolyzes with $t_{1/2} = 3.63 \times 10^5$ sec. The carbonyl group thus increases the hydrolysis rate by a factor of *ca.* 9000 times.

Enhancement in reaction rate can be explained in several ways. Hydration of the carbonyl group to give I, in which the rate enhancement would be due either to hydrogen-bonding assistance (eq 1) or to attack by the corresponding anion (eq 2). Alternatively, the active species could be the enol II, which could also participate *via* reactions of either type 1 or 2. Further considerations are activation of the phosphonyl group by an inductive effect or through orbital overlap with the carbonyl π-bonding electrons.



In the analogous hydrolysis of dimethylphosphoacetoin, in which, however, acetoin is the product of hydrolysis, Ramirez[5] indicated a preference for reaction path 2, *via* the enol corresponding to II, based upon his observation that certain cyclic saturated oxyphosphoranes hydrolyze in ether or benzene to yield cyclic phosphotriester. On the other hand, Cox and Farmer[6] argue in favor of path 1 as being consistent with their finding of the incorporation of one oxygen atom derived from solvent into the displaced dimethyl phosphate ion. In several cases where enolization cannot occur, rate enhancement of carboxylate ester hydrolysis by aldehydic carbonyl has been ascribed to the hydrated carbonyl group *via* route 2.[1d,7] In our study, compelling evidence against the enolization mechanisms is our observation that the hydrolysis of 1-anthraquinonyl *p*-nitrophenyl methylphosphonate in 25% *p*-dioxane–75% TRIS buffer of pH 8.00 was only 60 times slower than *p*-nitrophenyl phenacyl methylphosphonate under the same conditions. Furthermore, hydrolysis *via* the enol mechanisms is considered most unlikely since one should then expect to observe, to at least some extent, hydrolysis *via* the competitive pathway to give *p*-nitrophenyl methylphosphonate.[8] None was observed.[4] To be compatible with our results, reaction *via* intermediate I requires a very rapid preequilibrium step, since no deviations in reaction kinetics were observed, the first point being taken at 25 sec.[9] Based upon ultraviolet absorption in dioxane and dioxane–H_2O (50:50) the extent of hydration or hydroxyamination by 0.1 *M* TRIS (measured at pH 6.88) is at most minor.[10] Unlike the observation of Shalitin and Bernhard,[1d] addition of KCN had only a very small effect upon rate (20% enhancement at pH 7.9). On the other hand, in the presence of 0.02 *N* hydroxylamine hydrochloride at pH 3.5, a 10-fold increase in the rate of displacement of *p*-nitrophenol was observed.

It is noteworthy that with *ketonic group* participation in carboxylic ester hydrolysis, Newman and Hishida[7b] found an acceleration factor of *ca.* 10×, and Shalitin and Bernhard[1d] one of 40×, whereas in this study we have observed in phosphonate ester hydrolysis a rate enhancement several magnitudes larger. A detailed study of the reaction mechanism is in progress.

(3) Satisfactory elemental analyses were obtained on all compounds.
(4) Excellent first-order plots were obtained to >4 half-times. The production of *p*-nitrophenol, determined as the anion at 402 mμ, is stoichiometric; phenacyl methylphosphonic acid has been isolated in 80% yield.
(5) F. Ramirez, B. Hansen, and N. B. Desai, *J. Am. Chem. Soc.*, **84**, 4588 (1962).
(6) J. R. Cox, Jr., and J. J. Farmer, unpublished results, cited in ref 2.
(7) (a) M. L. Bender and M. S. Silver, *J. Am. Chem. Soc.*, **84**, 4589 (1962); (b) M. S. Newman and S. Hishida, *ibid.*, **84**, 3582 (1962).
(8) *p*-Nitrophenyl methylphosphonate anion is quite stable under these conditions, 0.25% hydrolysis in 27 hr at pH 7.9.
(9) Slow equilibrium with solvent was eliminated as a possibility since storage of the phosphonate ester in dioxane–water (25:1) for 4 days resulted in no change in hydrolysis rate.
(10) Maximum at 273 mμ unchanged in wavelength; reduced 3.7% in absorbance. Maximum at 243 mμ shifted to 248 mμ; no change in absorbance.

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Synthesis of the Tetranitratoborate Anion

Sir:

The simple nitrate of boron has never been isolated despite efforts by several investigators.[1-3] The products of the reactions are invariably B_2O_3 or possibly $BONO_3$. We wish to report the synthesis of tetramethylammonium tetranitratoborate, $[Me_4N][B(NO_3)_4]$, from the action of liquid dinitrogen tetroxide on the corresponding tetrachloride. The complex has proven

(1) M. Schmeisser, *Angew. Chem.*, **67**, 483 (1955).
(2) M. Schmeisser and K. Brandle, *ibid.*, **73**, 388 (1961).
(3) D. Lutzow, Dissertation, Munich, 1955.