and propane–hydrogen mixtures, respectively, is that of the very rapid further decomposition of a highly energetic product ion formed in a very exothermic reaction. An extreme example of this alternative is the complete failure so far to detect the dimer ion of the reactants.[1−3,5−8]

From all the reactions we have observed[1] that produce CH_5^+ (or its deuterated analog) we calculate $\Delta H_f(CH_5^+) \leq 234$ kcal./mole. Reactions 3 and 6 cannot, of course, be endothermic for this would mean that $\Delta H_f(CH_5^+) > 286$ kcal./mole which is an obvious inconsistency. Though we do not observe (4) and (7), we do not think it is because of energetic limitations, and furthermore Tal'roze and Frankevich[3] report evidence that (3), (4), (6), (7) do occur. However, neither we[8] nor others[3] have been able to detect the reaction

$$CH_4^+ + H_2O \longrightarrow CH_5^+ + OH \qquad (13)$$

which, if due to energetic limitations, permits the assignment of $\Delta H_f(CH_5^+) > 218$ kcal./mole. Expressing these energetic limits as proton affinities, P, we thus have

$$113 \text{ kcal./mole} < P(CH_4) < 129 \text{ kcal./mole}$$

in agreement with Tal'roze and Frankevich.[2,3]

For the reasons discussed above we do not believe that the failure to detect $C_2H_7^+$ ion in ethane–hydrogen mixtures permits the assignment of $P(C_2H_6) < 61$ kcal./mole.[2,3] Furthermore it seems unreasonably low when compared with the range found for methane. A more reasonable estimate can be made from the energetics of a well-established reaction occurring in methane,[5,9] namely

$$CH_3^+ + CH_4 \longrightarrow [C_2H_7^+] \longrightarrow C_2H_5^+ + H_2 \qquad (14)$$

The reaction must proceed through the $C_2H_7^+$ ion and so it must have at least a transitory existence. Moreover, for the reaction to be observable $\Delta H_f(C_2H_7^+)$ must be less than $\Sigma\Delta H_f$(reactants) but greater than $\Sigma\Delta H_f$(products). Hence,[10] 224 kcal./mole $< \Delta H_f(C_2H_7^+) <$ 244 kcal./mole which expressed as limits for the proton affinity of ethane is

$$101 \text{ kcal./mole} < P(C_2H_6) < 121 \text{ kcal./mole}$$

It is of interest that a value of $\Delta H_f(C_2H_7) > 224$ enables one to answer the question as to why a reaction analogous to (8) and (10) does not occur in ethane. For the reaction

$$C_2H_6^+ + C_2H_6 \longrightarrow C_2H_7^+ + C_2H_5 \qquad (15)$$

$\Delta H > 20$ kcal./mole, and thus has an activation energy that surely precludes its observation. Moreover, the reaction

$$H_2^+ + C_2H_6 \longrightarrow C_2H_5^+ + H_2 + H \qquad (16)$$

for which $\Delta H < 60$ kcal./mole may be the reason for the failure to detect the $C_2H_7^+$ ion.[2,3] The heat of reaction of

$$H_2^+ + CH_4 \longrightarrow CH_3^+ + H_2 + H \qquad (17)$$

is $\Delta H < 24$ so that (17) may be responsible for our inability to detect (3), (4), (6) and (7). Although we did not observe an increase in CH_3^+ with hydrogen pressure, this might well be due to our sensitivity limitations in detecting small differences between relatively large numbers.

Acknowledgment.—We wish to thank Mr. B. L. Clark for his assistance with the experimental work reported in this paper.

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[8] F. W. Lampe, F. H. Field and J. L. Franklin, THIS JOURNAL, **79**, 6132 (1957).

[9] D. O. Schissler and D. P. Stevenson, *J. Chem. Phys.*, **24**, 926 (1956).

[10] F. H. Field and J. L. Franklin, "Electron Impact Phenomena," Academic Press, Inc., New York, N. Y., 1957.

BAYTOWN, TEXAS

[CONTRIBUTION FROM THE EASTERN REGIONAL RESEARCH LABORATORY[1]]

Peroxides. VIII.[2] X-Ray Diffraction and Polarographic Study of *t*-Butyl Peresters and Diacyl Peroxides of Aliphatic Monobasic Acids[3]

BY LEONARD S. SILBERT, L. P. WITNAUER, DANIEL SWERN AND C. RICCIUTI[4]

RECEIVED NOVEMBER 12, 1958

Alternating series are obtained from long spacing and melting point data for the even and odd acyl chain members of diacyl peroxides and *t*-butyl peresters. The even membered diacyl peroxides have lower long spacing and higher melting point curves than the odd members. The even acyl chain membered *t*-butyl peresters have higher long spacing and melting point curves than the odd members. Long spacings have been redetermined for several acid anhydrides and reported for the first time for several *t*-butyl esters. Peroxide bond skew is revealed as a foreshortening of chain length. An exact computation of the O–O bond length in diacyl peroxides by a series comparison of the crystal data cannot be made because of uncertainties involving end packing and the degree to which the peroxide oxygen atoms are shielded as a result of skew by the attached carbonyl carbon atoms although a projected O–O group distance of 1.44 Å. has been derived. Half-wave potentials of −0.82 to −0.96 volt *vs.* S.C.E. for *t*-butyl peresters and −0.08 to −0.12 volt *vs.* S.C.E. for diacyl peroxides also have been obtained. Half-wave potentials for *t*-butyl peresters and diffusion current constants for diacyl peroxides decrease with chain ascension. The relations $i_d M^{1/2}$ = const. and $i_d M^{2/3}$ = const. are proposed to account equally well for the change of diffusion current constant with chain size in the diacyl peroxides. An order of decreasing bond strengths in peroxides based on half-wave potentials is di-*t*-butyl peroxide > *t*-butyl perester ≥ hydroperoxide > diacyl peroxide > peracid.

The availability of pure homologous diacyl peroxides and *t*-butyl peresters of long chain aliphatic monobasic acids, the preparation of which is described in a previous paper,[2] permitted a determination and study of their X-ray diffraction spectra (Tables I, II and III) and polarographic characteristics (Table IV). The results of these investigations are reported in this paper. Several acid an-

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[1] Eastern Utilization Research and Development Division, Agricultural Research Service, U. S. Department of Agriculture.

[2] Paper VII, *Anal. Chem.*, **30**, 385 (1958). Paper VI, THIS JOURNAL, **81**, 2364 (1959).

[3] Presented at the Fall Meeting of the American Chemical Society, Chicago, Illinois, September 7–12, 1958.

[4] Deceased.

TABLE I

LONG SPACINGS OF LONG-CHAIN DIACYL PEROXIDES

Diacyl peroxides	Spacing, Å.
Dipelargonyl	23.30
Didecanoyl	24.60
Dilauroyl	29.05
Ditridecanoyl	32.15
Dimyristoyl	33.40
Dipalmitoyl	37.75
Distearoyl	42.20

TABLE II

LONG SPACINGS OF LONG-CHAIN *t*-BUTYL PERESTERS

t-Butyl peresters	Spacing, Å.
Perpelargonate	12.45
Percaprate	13.40
Perlaurate	15.25
Pertridecanoate	15.73
Permyristate	17.00
Perpalmitate	18.80
Perstearate	20.55

TABLE III

CRYSTAL DATA FOR PEROXIDE AND NON-PEROXIDE ANALOGS

Compound	Slope[a]	Tilt, β	Corrected intercept, Å.[b]
Diacyl peroxides			
Even	1.098	57° 13′	3.18
Odd	1.106	57° 53′	4.00
Anhydrides			
Even	1.054	53° 49′[c]	2.78
Odd[d]	0.9525	46° 50′[e]	1.52
t-Butyl peresters, even	.8925	43° 7′	6.59
t-Butyl esters, even	.9375	45° 53′	7.31

[a] Equal to change in long spacing per carbon atom. [b] Intercept/sin β corrects the intercept for the slope and gives the end packing plus all linear chain atoms exclusive of the fatty acid carbons. [c] Malkin (ref. 7, p. 14) reports 49° 54′. [d] Malkin's data (ref. 7, p. 14). [e] Recomputed from Malkin's data by least squares treatment. Malkin reports 46° 3′ (ref. 7, p. 14).

TABLE IV

POLAROGRAPHIC CHARACTERISTICS OF *t*-BUTYL PERESTERS, DIACYL PEROXIDES, AND ALKYL HYDROPEROXIDES

Compound	$E_{1/2}$, v. *vs.* S.C.E.	i_d/C[a]	$\frac{i_d}{C} M^{2/3}$	$\frac{i_d}{C} M^{1/2}$
		t-Butyl peresters[b]		
Perpelargonate	−0.96	10.7		
Percaprate	− .90	10.9		
Perlaurate	− .87	10.0		
Permyristate	− .82	10.5		
		Diacyl peroxides[b]		
Dipelargonyl	−0.10	9.1	421	161
Didecanoyl	− .10	10.0	479	185
Dilauroyl	− .09	9.6	519	192
Dimyristoyl	− .12	8.2	484	175
Dipalmitoyl	− .10	7.7	494	175
Distearoyl	− .08	6.2	425	148
		C_{10}—C_{18} av.	494 ± 3.6%	182 ± 4.6%
		C_9—C_{18} av.	470 ± 8.3%	172 ± 9.3%
		n-Alkyl hydroperoxides[c]		
Pentyl	−0.20	7.3	162	74.5
Hexyl	− .12	6.9	166	75.2
Octyl	− .02	6.0	167	72.3
Nonyl	− .01	5.8	171	73.7
		Av.	166.5 ± 2.2%	73.9 ± 1.6%

[a] Diffusion current constant exclusive of capillary constant. [b] Benzene–methanol (1:1) solution. [c] Water–ethanol (4:1) solution.[18]

hydrides and *t*-butyl esters (Table V), which are the non-peroxide analogs of diacyl peroxides and *t*-butyl esters, respectively, also were prepared. Their long spacings were obtained for comparison in an attempt to determine the O–O bond length and O–O group distance along the zig-zag axis. Polarographic half-wave potentials and diffusion current constants obtained for the two peroxide series yielded some useful and interesting relationships which also are described.

Comparative X-Ray Diffraction Method.—X-Ray powder data were obtained on the peroxides and the analogous non-peroxide compounds. Crystallization in identical packing habits by analogous pairs of peroxide and non-peroxide compounds should permit a determination of some of the structural features associated with the peroxide linkage. The comparative method depends upon the existence of both a linear and a parallel relationship for plots of long-spacings against carbon atoms (or methylene groups including carbonyl carbon) for the analogs. The slopes, representing the increase in long spacing per carbon for compounds which crystallize at angles β inclined to the basal plane, will be less than the projected distance[5] of 1.306 Å. observed for long chains which crystallize in a vertical (90°) arrangement. The observed long spacings which include the end packing contribution, if divided by sin β, will yield the chain length along the *C*-axis. Extrapolation of the long spacing plots to zero carbon content for the anhydrides and diacyl peroxides leaves an intercept value,[6] which represents all linear or chain linked non-carbon atoms plus the long spacing contribution of each terminal hydrogen on the hydrocarbon tails. The intercept value must be divided by sin β to obtain a corrected intercept value (Table III), in order to obtain its contribution to the chain length.

The end packing, which represents the projected distance of two terminal hydrogen atoms, is reported to be 2.2 Å.[7] for hydrocarbons and ketones that crystallize in vertical forms. However, the end packing for inclined forms, after correcting for tilt, may differ from the value for the vertical forms because strong polar side chain forces, the degree of chain linearity and steric hindrance effects, which are present in the compounds under study, should influence the terminal arrangements.

The corrected intercept value for the anhydrides is the sum of the projected distance of the end packing of the hydrocarbon tails and the ether-like oxygen atoms within the chain. The end packing may then be determined by subtracting the calculated projected diameter of the anhydride oxygen from the corrected intercept value. Similarly, the corrected intercept value for the diacyl peroxides is the sum of the projected end packing distance and the projected O–O group distance. If it is assumed that the anhydrides and diacyl peroxides have the same end packing, the projected O–O group distance is then obtained by difference.

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(5) Defined as the vertical distance measured between the centers of atoms. A C–C projected distance is less than the normal C–C bond distance of 1.54 Å. due to the zig-zag arrangement of linear atoms.

(6) Computed by least squares.

(7) T. Malkin, "Progress in the Chemistry of Fats and Other Lipids," Vol. I, Academic Press, Inc., New York, N. Y., 1952, pp. 1–17.

TABLE V

CHARACTERISTICS OF *t*-BUTYL ESTERS AND ACID ANHYDRIDES

Compound	M.p., °C.		Long spacings, Å.		Analyses, %			
					Carbon		Hydrogen	
	Found[a]	Reported[b]	Found	Reported[c]	Calcd.	Found	Calcd.	Found
t-Butyl esters								
Myristate	12.6–13.0	....	18.40		75.99	75.87	12.76	12.91
Palmitate	23.5–24.0	....	20.20		76.86	76.65	12.90	12.31
Stearate	31.8–32.0	....	22.15		77.58	77.57	13.02	12.89
Anhydrides					Purity, %[d]			
Lauric	41.0–41.5	41.2–41.5	27.55	27.9	99.8			
Palmitic	62.0–62.8	63.8–64.0	36.00	35.8	98.0			
Stearic	69.8–70.0	70.0–70.4	40.20	39.8	99.7			

[a] Fisher–Johns melting point apparatus. [b] Reference 22. [c] Reference 7, p. 13. [d] Reference 23, 10^{-3} mole of sample was dissolved in 10 ml. of chloroform prior to analysis.

Even Anhydrides and Even Diacyl Peroxides.—The long spacings of the even diacyl peroxides are slightly larger than those of the even anhydrides (Fig. 1). Slopes, tilts and corrected intercept values (Table III) indicate the even peroxides to be less tilted and longer by 0.4 Å. along the *C*-axis than the even anhydrides. An end packing of 1.74 Å. results from the calculated projected chain-linked oxygen diameter (1.04 Å.)[8] and the corrected intercept value (2.78 Å.).

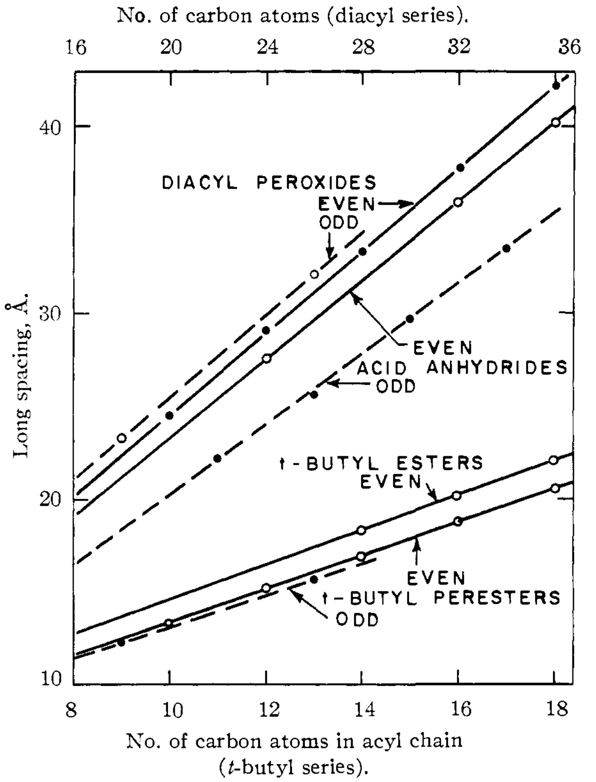

Fig. 1.—Plots of long spacings against number of carbon atoms for peroxide and non-peroxide analogs.

Dipole moment measurements[9] obtained for acetic anhydride give a resultant moment which shows restriction of rotation about the two C–O axes. Although the dipole moment is the resultant of all possible rotations in the liquid state, crystalline anhydrides would be expected to maintain a similar dihedral configuration of maximum stability. Stuart–Briegleb models reveal that a slight foreshortening of the chain occurs when one acyl group is rotated into an oblique configuration (approximately 100°) while maintaining the alkyl group in its extended linear form (Fig. 2A).

If even diacyl peroxides have the same end packing as even anhydrides, a projected O–O group distance of 1.44 Å. is derived. If a normal chain-extended zig-zag configuration were applicable to the peroxide linkage, the projected distance for the peroxide oxygens would be 2.1 Å.[10] or 0.66 Å. larger than the derived value. Regardless of any assumptions one must make about end packing and anhydride oxygen contributions, this observed peroxide foreshortening is real and constitutes further evidence of the skewed O–O bond linkage, computed by Penney and Sutherland for hydrogen peroxide.[11]

This skewing effect recently has been demonstrated from dipole moment measurements on several aliphatic and aromatic peroxide derivatives.[12] The dipole moments, observed to be lower than the anhydride values,[9] have been used to construct a Penney–Sutherland structure with a dihedral angle of 100° between the C–O–O planes, coplanar configurations in each $\text{C}–\underset{\underset{\text{O}}{\|}}{\text{C}}–\text{O}$ grouping and with both carbonyl groups oriented inward (toward O–O group) (Figs. 2B and 3). This vertically inclined angle has the over-all effect of foreshortening the chain length as revealed in Stuart–Briegleb models. When viewed in a projected distance, the O–O bond skew has the effect of telescoping two atoms to give the peroxide a superficial physical resemblance to the corresponding anhydride.

The projected O–O group distance of 1.44 Å. must not be confused with the O–O bond distance of 1.4[11]–1.45 Å.,[13] for the group distance is the lin-

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[8] Calculated from the trigonometric relationship involving a C–O distance of 1.43 Å., a projected carbon radius of 0.65 Å. (calculated as one-half the C–C projected distance) and a C–O–C bond angle of 110°.

[9] P. F. Oesper and C. P. Smyth, THIS JOURNAL, **64**, 768 (1942).

[10] Based on a projected oxygen radius of 0.52 Å. (calculated from the C–O bond distance), a covalent oxygen radius of 0.65 Å. and tetrahedral valency.

[11] W. G. Penney and G. B. B. M. Sutherland, *Trans. Faraday Soc.*, **30**, 898 (1934); *J. Chem. Phys.*, **2**, 492 (1934).

[12] W. Lobunez, J. R. Rittenhouse and J. Miller, THIS JOURNAL, **80**, 3505 (1958); J. R. Rittenhouse, W. Lobunez, D. Swern and J. G. Miller, *ibid.*, **80**, 4850 (1958).

[13] V. Kassatochkin, S. Perlina and K. Ablesova, *Compt. rend.* (*Doklady*), **47**, 36 (1945).

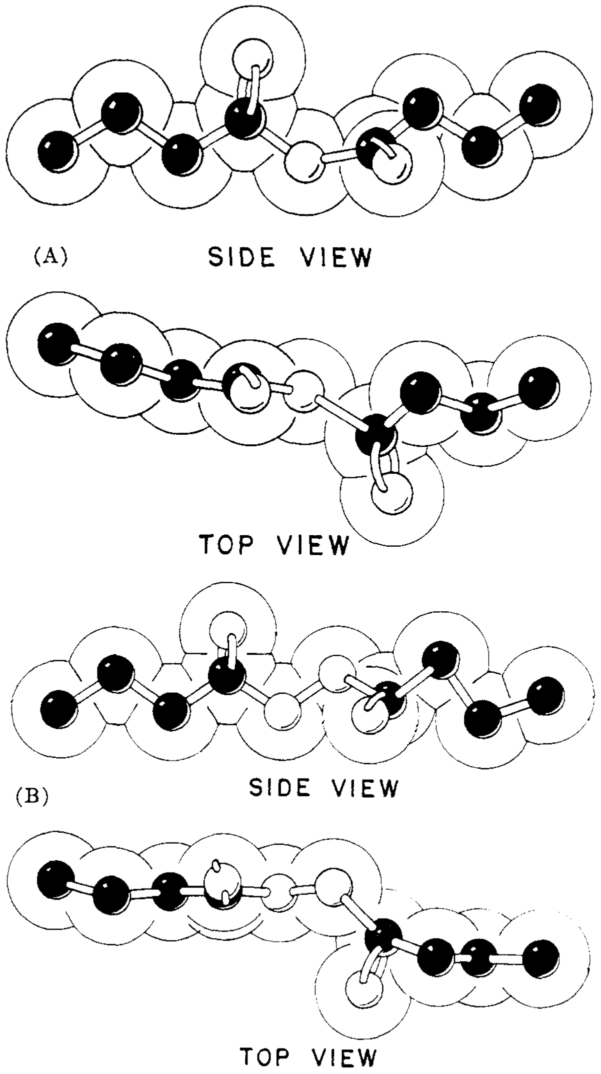

Fig. 2.—Models (shortened chains) of (A) acid anhydride and (B) diacyl peroxide combining the ball and rod representation with van der Waals radii (hydrogens omitted) for increased clarity of the foreshortened effect: closed circles, carbon; open circles, oxygen.

ear dimension of the peroxide less the length shielded by the attached carbons. An accurate O–O bond distance could not be derived directly from the projected O–O group distance because of end packing uncertainties and the degree to which the peroxide oxygens are shielded. The observed foreshortening of 0.66 Å. corresponds to a dihedral angle of 123° which is in fair agreement, in view of the assumptions involved, with the dihedral angles of 100° derived from the dipole moment study.[12]

It has been assumed in the discussion that the end packing is the same for both even carbon series. In order to determine the validity of this assumption, some schematic arrangements of peroxides and non-peroxide analogs similar to the terminal methyl group arrangements depicted for hydrocarbons[7] were studied. The skewed nature of the peroxide group and the oblique configuration of the anhydride group do not permit a simple comparison of terminal methyl planes between odd and even carbon homologs, thereby complicating any schematic comparison. However, the models of Fig. 2A and 2B attempt to show one probable chain alignment relative to their central oxygen groups in order to demonstrate the similarities of these two series.

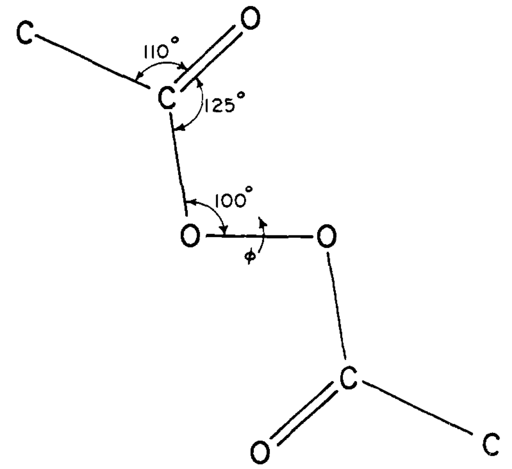

Fig. 3.—Structure of diacyl peroxide group: $\mathrm{C{-}\underset{\underset{O}{\|}}{C}{-}O}$ coplanar; φ (dihedral) between C—O—O planes 100°.

Even and Odd Diacyl Peroxides.—Alternation of long spacings is observed between these two series with the odd carbon members having slightly larger long spacings. Tilts for both series are nearly identical, although examination of only two odd carbon peroxides restricts the certainty of this determination. If the configuration about the O–O linkage is the same for both even and odd members, the only difference in structures will be the degree of end packing. The corrected intercept values for the even and odd members are 3.18 and 4.00 Å., respectively. The end packing for odd-membered series is, therefore, 0.8 Å. longer than for the even-membered series. This alternation should be reflected and, therefore, validated in a lower melting point curve for the odd-membered peroxides. This property has been experimentally observed (Fig. 4).

Even and Odd Anhydrides.—Long spacing values of the even and odd members are plotted in Fig. 1. The values for the odd members were taken from the literature.[7] The two series differ sharply in their long spacings, angles of tilt and corrected intercept values (Table III) with the odd-membered series having the smaller values. The end packing value for the odd members, calculated in the manner described for even anhydrides, is approximately 0.5 Å. This value is unexpectedly small and would indicate that the ends of odd members pack more closely than those of the even members. Melting point data[14] (Fig. 4) support this view, since the melting point curve for the odd-membered series is slightly higher than that for the even-membered series, leading to a reversed alternation. The data lead to the conclusion that the anhydride structures are not isomorphous, so that a comparison between

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[14] J. M. Wallace, Jr., and J. E. Copenhaver, This Journal, **63**, 699 (1941).

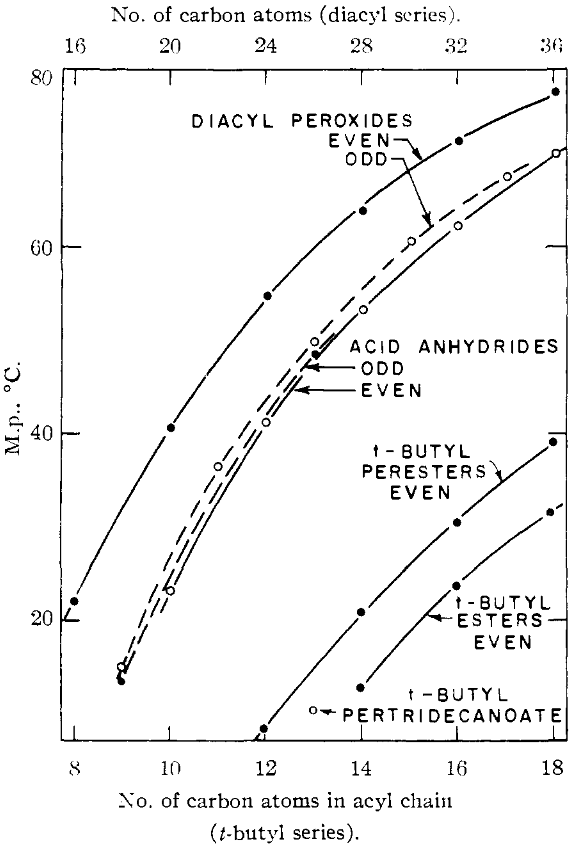

Fig. 4.—Plots of melting points against number of carbon atoms for peroxide and non-peroxide analogs.

odd anhydrides and odd diacyl peroxides cannot be made.

t-**Butyl Esters and Peresters.**—*t*-Butyl esters and peresters crystallize in highly tilted layers as evidenced by the small change in long spacing per carbon atom (Fig. 1 and Table III), which is less than 1 Å. per methylene. Long spacings of the even *t*-butyl esters, which are larger than those of *t*-butyl peresters, is a reverse of the relationship found for the even diacyl peroxides and anhydrides. In addition, long spacings of the odd *t*-butyl peresters are slightly less than those of the even members, which is also the reverse of that observed for the even and odd diacyl peroxides. The melting point of *t*-butyl pertridecanoate falls below the even series curve to confirm that the even series is the thermodynamically more stable one. Angles of tilt for the even *t*-butyl esters and peresters are similar but are not reported for the odd *t*-butyl peresters because of some uncertainty about the crystalline form of *t*-butyl perpelargonate. The crystal structures of *t*-butyl esters and peresters are apparently different.

Because *t*-butyl esters contain only one carbonyl group, π-electron repulsion is absent, in contrast to anhydrides. The foreshortening observed in anhydrides would then be absent in the esters but would still be present in the peresters as a result of peroxide group skew. Comparison of *t*-butyl groups in the ester and perester Stuart–Briegleb models also reveals a difference in the position of the *t*-butyl group relative to the chain. The *t*-butyl group in the ester models is linearly disposed and restricted in rotation by steric hindrance. In the perester models, the *t*-butyl group is angularly disposed because of the O–O skew and, therefore, is free to rotate. The *t*-butyl group disposition would then be expected to effect an end packing difference for these two series. A complete elucidation of the different series structures will require single crystal studies.

Polarographic Behavior. Peresters.—The polarographic characteristics of four *t*-butyl peresters are listed in Table IV. These peresters, which have half-wave potentials of -0.82 to -0.96 volt *vs.* S.C.E., reduce with nearly the same ease as hydroperoxides ($E_{1/2}$ -0.61 to -0.96 volt *vs.* S.C.E.)[15] but are more difficult to reduce than peracids ($E_{1/2}$ 0.00 to -0.06 volt *vs.* S.C.E.).[16] *t*-Butyl peresters are then more resistant to polarographic reduction than the corresponding peracids. This can be attributed to the electron-releasing effect of the *t*-butyl group which increases the electron-density of the O–O link, thereby making reduction (electron gain) more difficult. The half-wave potential relationship also supports the view that peresters behave as derivatives of hydroperoxides rather than of peracids, which is chemically substantiated by formation of *t*-butyl hydroperoxide as product rather than perbenzoic acid from the basic methanolysis of *t*-butyl perbenzoate.[17]

It is apparent from Table IV that the half-wave potentials of *t*-butyl peresters decrease with molecular weight increase. In fact, a 16% decrease is observed between the pelargonate and myristate peresters. This dependency of half-wave potential on molecular weight also was detected by Skoog and Lauwzecha[18] on several homologous alkyl hydroperoxides. No ready explanation is available from the data for this dependency, since the addition of methylene groups to an alkyl chain of five or more carbon atoms would be expected to have little effect on the electron density and, therefore, on the strength of the O–O bond. Additional work in organic polarography is necessary before this phenomenon can be satisfactorily explained.

An indication of a decrease in the diffusion current constant with increase in chain length is noted for this series. A real diffusion current constant–chain length relationship has been reported for homologous hydroperoxide series in which the diffusion current constant decreased 20% from 1-pentyl to 1-nonyl hydroperoxide.[18] The dependency of diffusion current constant on chain length is more striking in the diacyl peroxide series (see below). The diffusion current constants obtained for peresters show that a two-electron reduction occurs, as in the case of hydroperoxides.

Diacyl Peroxides.—Half-wave potentials for the six homologous diacyl peroxides (Table IV) remain constant with increasing molecular weight (-0.08 to -0.12 volt *vs.* S.C.E.), in contrast to the peresters. The possibility of the existence of a pro-

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(15) C. O. Willits, C. Ricciuti, H. B. Knight and D. Swern, *Anal. Chem.*, **24**, 785 (1952).

(16) W. E. Parker, C. Ricciuti, C. L. Ogg and D. Swern, THIS JOURNAL, **77**, 4037 (1955).

(17) N. A. Milas and D. M. Surgenor, *ibid.*, **68**, 642 (1946).

(18) D. A. Skoog and A. B. H. Lauwzecha, *Anal. Chem.*, **28**, 825 (1956).

gression for shorter chain aliphatic diacyl peroxides cannot be overlooked, since the observed constant value might represent a limit for the longer chain peroxides. The diacyl peroxides are reduced at less negative half-wave potentials than peresters. This can be explained by the fact that the O–O link in these peroxides is flanked by two electron-withdrawing carbonyl groups which lower the electron density, thus permitting facile reduction.

Diffusion current constants for the diacyl peroxides show a marked decline with molecular weight increase, the value for distearoyl peroxide being 38% less than that for didecanoyl peroxide. This relationship is in general accord with the fundamental concepts of diffusion constants. The Stokes–Einstein equation relates the diffusion coefficient (D) of uncharged compounds in an inverse proportionality to the cube root of the apparent molar volume (V) (molecular weight/density) in the pure solid state and the viscosity (η) of the solvent[19]

$$D = \frac{2.96 \times 10^{-7}}{\eta V^{1/3}} \text{ cm.}^2 \text{ sec.}^{-1} \text{ at } 25^\circ$$

Although the equation is valid primarily for spherical colloid particles and certain types of large molecules, the proportionality will be qualitatively valid for non-spherical particles. The Stokes–Einstein equation predicts that the diffusion coefficient D should be inversely proportional to the viscosity coefficient of the medium and to changes in the size of the solvated species. Because the diffusion current is directly proportional to $D^{1/2}$, the relation $i_d\eta^{1/2}M^{1/6}/C$ = const., where I_d is the diffusion current and C is the millimolar concentration, should be a good approximation since the one-sixth power of the densities for a homologous series will be essentially constant.

The viscosity of long chain compounds is known to be related to carbon chain length (molecular weight) as illustrated by one of several such empirical equations

$$\eta = KM + \alpha$$

where K and α are constants for a homologous series.[20]

Because viscosity and molar volume are both proportional to molecular weight, the diffusion coefficient should be related to M by the relation $D \sim (1/M)^{4/3}$, for small α and for carbon chains of less than polymeric size. The relation $i_dM^{2/3}/C$ = const. should then hold where changes in D are influenced by changes in viscosity of solution and size of the solvated species. Table IV illustrates the constancy of this relation with the respective per cent. standard deviations for the current peroxide series and for hydroperoxides taken from the literature.[18] The relation $i_dM^{1/2}/C$ = const. is of equivalent constancy illustrating the viscosity effect to be more important than the apparent molar volume on diffusion currents, while other powers of M, such as first, one-third and one-sixth, were tried and found to be less satisfactory in this relation. Although the present data may not be sufficiently accurate to validate completely either or both of the two relations $i_dM^{2/3}/C$ and $i_dM^{1/2}/C$, they account nearly quantitatively for a decrease in diffusion current constant as the diacyl peroxide series is ascended.

The diffusion current constants reveal that two electrons are involved in the reduction of the diacyl peroxides. The half-wave potentials thus far determined for aliphatic peroxide derivatives indicate that an order of decreasing bond strengths can be formulated to be di-*t*-butyl peroxide > *t*-butyl perester ≥ hydroperoxide > diacyl peroxide > peracid. Although no polarographic data are available on *n*-alkyl hydroperoxides in benzene-methanol mixtures, considerations of the structural effects on $E_{1/2}$ for hydroperoxides which have been studied[15] indicate that these compounds should be reduced at less negative half-wave potentials than *t*-butyl peresters.

Experimental

Diacyl Peroxides and *t*-Butyl Peresters.—These were prepared as previously described.[2] Those compounds having melting points below room temperature were freed of solvent by vacuum-drying in flasks maintained below the fusion temperatures.

***t*-Butyl Esters.**—These were prepared by a modification of the method described for the preparation of *t*-butyl benzoate.[21] Pyridine (12 g., 0.15 mole) and *t*-butyl alcohol (11 g., 0.15 mole) were dissolved in ethyl ether (100 ml.), cooled to 5° in an ice-bath and stearoyl chloride was added dropwise, maintaining the temperature of reaction below 10° during the addition. The mixture was allowed to stand at room temperature overnight. The mixture was diluted with ether (200 ml.), washed with dilute hydrochloric acid, with 10% potassium bicarbonate solution until free of fatty acid and then dried over anhydrous sodium sulfate. The volume of the ether solution was reduced to 50 ml. and the compound was crystallized at −15°. The *t*-butyl stearate was recrystallized from methanol at 3°. *t*-Butyl palmitate and myristate were prepared similarly and recrystallized from methanol at 3°. The constants of the *t*-butyl esters, also new compounds, are listed in Table V.

Acid Anhydrides.—Those of stearic, palmitic and lauric acids were prepared from the redistribution reaction of acyl chlorides and acetic anhydride[22] and recrystallized from chloroform–petroleum ether solutions. Purity of the anhydrides was determined by reaction with morpholine[23]; samples were dissolved in chloroform prior to analysis. Constants for the anhydrides are listed in Table V.

Melting points were determined on a Fisher–Johns[24] melting point apparatus. Crystals with melting points between 0° and room temperatures were determined on the Fisher–Johns block in a cold room thermostatically controlled at 2° as previously described.[2]

X-Ray Diffraction.—Long spacings were obtained with a General Electric XRD-3 direct recording unit using filtered Cu Kα radiation (λ 1.5405 Å.), 1° beam slit, 0.1° detector slit, high resolution soller slit, scanning speed 2°/min., chart speed 60 in./hr. linear scale, 4 sec. time constant. To prepare the compounds for X-ray examination, the solvent-crystallized compounds were finely ground and pressed onto a glass slide exposing an area approximately 1/2″ × 1/2″ to the X-ray beam. Diffraction patterns of compounds having melting points below room temperature were ob-

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(24) Reference to commercial products is not intended to be a recommendation of these products by the U. S. Department of Agriculture over others not mentioned.

tained by maintaining the compounds on a cold stage at −70°.

Polarographic Procedure.—A Sargent Model XXI polarograph was used to obtain the current–voltage curves. The polarographic H-cell used has been previously described.[15] The capillary had m and t values of 3.09 mg. per second and 1.54 seconds, respectively, yielding a capillary constant of 2.28 $mg.^{2/3}$ $sec.^{-1/2}$. These values were obtained using an open circuit with the capillary immersed in the non-aqueous electrolyte solution maintained at 25 ± 0.1°. The electrolytic solution was 0.3 M lithium chloride in equal volumes of absolute methanol and benzene. Solutions of known concentrations (0.6 to 3.0 × 10^{-3} M) of the peresters and peroxides were prepared, aliquots transferred to the H-cell and polarograms obtained. Three to six solutions of different concentrations were prepared for each compound and the average values for the half-wave potentials and diffusion current constants were then obtained. To minimize the interference of extremely high maxima exhibited by concentrated solutions of peroxides, dilute solutions were used. At these low concentrations the maxima were sufficiently suppressed so that reliable wave height measurements could be obtained provided the wave heights were measured in the flat portion of the curves.

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PHILADELPHIA 18, PENNA.

[CONTRIBUTION FROM THE DEPARTMENT OF CHEMISTRY, STATE UNIVERSITY OF IOWA]

Physicochemical Study of Metrazole and of Metrazole Derivatives

BY ALEXANDER I. POPOV AND ROGER D. HOLM

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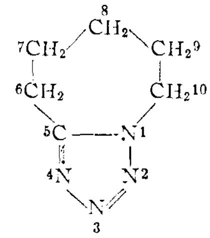
Stability of silver complexes formed by metrazole, 8-*t*-butylmetrazole, 8-*sec*-butylmetrazole, 7-methyl-9-isopropylmetrazole, 7-methyl-10-isopropylmetrazole and 1-cyclohexyl-5-methyltetrazole were determined potentiometrically in acetonitrile solutions. These complexes, of the general formula $(Met)_2Ag^+$, were all more or less equally unstable with the pK_d values being 2.14, 2.14, 2.18, 2.22, 2.19 and 2.26, respectively. No correlation was observed between the convulsive properties of the metrazoles and their complexing ability with silver ion. Solid metrazole–silver nitrate complex was prepared and its infrared spectrum was determined in the 5000–450 cm.$^{-1}$ region and was compared with the spectrum of metrazole. Polarographic study on cadmium–, thallium– and cobalt–metrazole complexes in aqueous solutions showed that complexes were essentially completely dissociated. Metrazole was found to have a weak proton affinity and can be titrated potentiometrically in glacial acetic acid with perchloric acid solutions.

Introduction

It was pointed out in the previous communication,[1] that although metrazole is known to be a strong convulsive agent and has had a long clinical history, its chemical and especially its physicochemical properties have not been investigated to any significant extent. While substituted metrazole derivatives are less well known, Gross and Featherstone[2] reported in a number of papers their studies on the pharmacological properties of a number of such compounds. These authors have found that an addition of a methyl group to the pentamethylene chain of metrazole increases the stimulating action of the parent compound. As the methyl group is moved progressively toward the symmetrical 8-position, the stimulation becomes more pronounced. An increase in the size of the substituent group in the 8-position shows a variable effect; thus while 8-isopropylmetrazole has a minimum convulsant dose of 3 mg./kg. (as compared with 25 mg./kg. for metrazole), 8-*sec*-butylmetrazole and 8-*t*-amylmetrazole show a depressant rather than a stimulating activity. Substitution of larger groups in other positions of the pentamethylene chain likewise decreases the convulsant activity of metrazole; for example, 7-methyl-10-isopropylmetrazole has a minimum convulsant dose of 750 mg./kg. Obviously, the physico-chemical properties of substituted metrazoles are not known any better than those of the parent compound.



It was of interest to continue the study of nucleophilic properties of metrazole and of its derivatives, especially with compounds of varying convulsant activity, in order to see whether there is any correlation between these properties and pharmacological action. Silver ion usually forms quite stable complexes with heterocyclic amines, but while some solid silver–metrazole complexes have been reported[3] in the literature, formation of such complexes in solution as well as their dissociation constants have not been determined. This was the main object in the present study.

Experimental Part

Reagents.—Metrazole (Knoll's "Metrazol") was obtained from the Knoll Pharmaceutical Company, Orange, N. J., and was purified as described in the previous publication.[1] Metrazole derivatives were obtained from the same source and were as follows: 8-*sec*-butylmetrazole, m.p. 68–69°, lit. val.[4] 70°; 8-*t*-butylmetrazole, m.p. 130–132°,

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