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Thiolcarbamates from the Reaction of Dialkylamines with Carbon Monoxide and Sulfur

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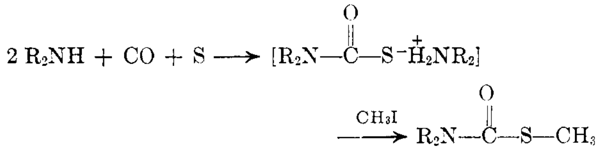
A new synthesis for mono-, di-, and trisubstituted ureas involving the reaction of carbon monoxide and sulfur with amines has been reported recently.[1] It was of interest, therefore, to investigate the hitherto unreported reaction of dialkylamines with carbon monoxide and sulfur. It was found that di-*n*-butylamine and diisopropylamine reacted to yield their respective dialkylammonium dialkylthiolcarbamates in substantial yields.



$$2\,R_2NH + CO + S \longrightarrow [R_2N{-}\overset{\overset{\displaystyle O}{\|}}{C}{-}S^{-}\overset{+}{H_2}NR_2] \xrightarrow{CH_3I} R_2N{-}\overset{\overset{\displaystyle O}{\|}}{C}{-}S{-}CH_3$$

R = isopropyl or *n*-butyl

EXPERIMENTAL[2,3]

Reaction of diisopropylamine with carbon monoxide and sulfur followed by reaction with methyl iodide. A mixture of diisopropylamine (101 g., 1 mole), sulfur (32 g., 1 mole), and tetrahydrofuran (200 ml.) was charged to a 1.4-l. bottom-stirred autoclave which was purged with nitrogen and then sealed. Carbon monoxide was injected into the autoclave until a pressure of 300 p.s.i. was reached. The stirred mixture was heated to 120° during 35 min. The temperature of the mixture was then maintained at 120° and the pressure at 400 p.s.i. by occasional injection of carbon monoxide during 1 hr. The autoclave was cooled to 0° and the gases were vented. Methyl iodide (142 g., 1 mole) was added dropwise to the stirred mixture at 0–10°. The thick slurry was stirred at room temperature for 3 hr. The mixture was filtered, and the crystals were washed with ether. Ether was added to the filtrate until no more crystals separated. The mixture was filtered and the filtrate was evaporated to an oil which was distilled to yield *S*-methyl diisopropylthiolcarbamate (53 g., 0.30 mole, 60% yield), b.p. 92–96.5°/14 mm., n_D^{25} 1.4831.

The infrared spectrum had a peak at 6.05 μ (C=O) and was identical with that of a sample prepared in the same manner having b.p. 96–96.5°/14 mm., n_D^{25} 1.4822.

Anal. Calcd. for $C_8H_{17}NOS$: C, 54.81; H, 9.78; N, 7.99; S, 18.22. Found: C, 54.99; H, 9.42; N, 7.92; S, 18.57.

In another experiment the mixture of crystals and liquid obtained from the reaction of diisopropylamine with carbon monoxide and sulfur was cooled to −10°. The slurry was filtered; the crystals were washed with ether (200 ml.) and pressed dry with a filter dam for 1 hr. The filtrate was cooled to −80° for 1 hr. The solid which separated was combined with the first crop to yield diisopropylammonium diisopropylthiolcarbamate (79.6 g., 0.30 mole, 60% yield). The infrared spectrum was identical with that of an authentic sample prepared from the reaction of carbonyl sulfide with diisopropylamine.

Reaction of di-n-butylamine with carbon monoxide and sulfur followed by methyl iodide. A mixture of di-*n*-butylamine (129 g., 1 mole), sulfur (32 g., 1 mole), and tetrahydrofuran (200 ml.) was treated in a similar manner to the case of diisopropylamine. The reaction mixture was heated to 90° during 30 min. at a carbon monoxide pressure of 200 p.s.i. The autoclave was maintained at a temperature of 90–94° and 200 p.s.i. for 10 min., then cooled to room temperature. Methyl iodide (142 g., 1 mole) was added under the usual conditions. There was obtained *S*-methyl di-*n*-butylthiolcarbamate (62.5 g., 0.31 mole, 62% yield), b.p. 79–80°/0.2 mm., n_D^{25} 1.4781 (lit.[4] b.p. 144.5–146°/20 mm.; n_D^{30} 1.4761).

The infrared spectrum had a peak at 6.1 μ (C=O) and was identical with that of a sample prepared in the same manner.

Anal. Calcd. for $C_{10}H_{21}NOS$: C, 59.07; H, 10.41; N, 6.89 S, 15.77. Found: C, 59.05; H, 10.57; N, 6.71; S, 15.77.

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(1) (a) F. Applegath, M. Barnes, and R. Franz, U. S. Pat. **2,857,430** (1958); *Chem. Abstr.*, **53**, 5296h (1959). (b) *Cf.*, F. Applegath and R. Franz. U. S. Pat. **2,874,149** (1959); *Chem. Abstr.*, **53**, 12187f (1959). (c) *Cf.*, F. Applegath and R. Franz, U. S. Pat. **2,857,392** (1958); *Chem. Abstr.*, **53**, 5286e (1959).

(2) All boiling points are uncorrected.

(3) Elemental analyses were performed by the Galbraith Laboratories, P. O. Box 4187, Knoxville, Tenn.

(4) H. Tilles, *J. Am. Chem. Soc.*, **81**, 714 (1959).

The Structure of the Crystalline Peroxide Formed in the Oxidation of Acetaldehyde

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Wieland[1] first proposed an addition product of peracetic acid and acetaldehyde to be an intermediate in the liquid-phase autoxidation of acetaldehyde to acetic acid, and Lösch[2] later isolated, analyzed, and determined the physical properties of such an intermediate. Since then there has been controversy over its structure. The following structures for this peroxide intermediate have been proposed. Wieland,[1] Lubarsky and Kagen,[3] Lösch,[2] Golding,[4]

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(1) H. Wieland, *Ber.*, **54**, 2357 (1921).

(2) H. Lösch, P.B. 52007, pp. 23, 101. Office of Technical Service, U. S. Department of Commerce, Washington, D. C.

(3) G. D. Lubarsky and M. J. Kagen, *J. Phys. Chem.*, **39**, 847 (1935).

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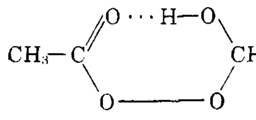
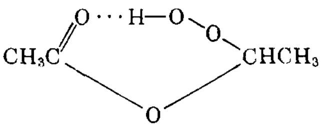


I



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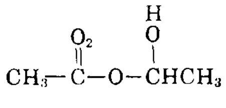

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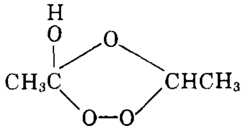
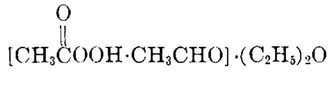


IV

and the present authors,[5] among others, have assigned structure I to this peroxide. Structure II has been proposed by Bawn and Williamson[6] and by Vasilyev, Terenin, and Emanuel,[7] structure III by D'Ans, Dossow, and Mattner,[8] and structure IV by Rieche.[9] On two properties of this intermediate there is general agreement; *i.e.*, it is a peroxide, and its empirical formula is $C_4H_8O_4$. This formula, well supported by analytical data,[2,4] corresponds to the elements of one molecule of peracetic acid and one molecule of acetaldehyde or, alternatively, to the elements of two molecules of acetaldehyde and one molecule of oxygen.

One clue to the structure would have been furnished by synthesizing this peroxide from peracetic acid and acetaldehyde; however, early attempts[3,7,8] to do this, in toluene solution, gave an apparently different peroxide—one which melted at −20°. In contrast, the low-temperature liquid-phase oxidation of acetaldehyde gave a compound which melted at 22°.[2,6,8] Bawn and Williamson,[6] on the basis of the analysis of decomposition products, suggested that the intermediate peroxide (m.p. −20°) corresponded to structure II and that when it was prepared by the oxidation of acetaldehyde it crystallized from solution with one molecule of acetaldehyde of crystallization to give the compound melting at 22°. D'Ans, Dossow, and Mattner[8] isolated a compound with a melting point of 8° from the reaction of peracetic acid and acetaldehyde in ether solution and ascribed to it the formula,



$$[CH_3\overset{\underset{\|}{O}}{C}OOH\cdot CH_3CHO]\cdot(C_2H_5)_2O$$

The present authors[5] found that the product from the low-temperature, liquid-phase oxidation of acetaldehyde with molecular oxygen was identical with the product obtained from peracetic acid and acetaldehyde in ethyl acetate solution. In each case, the product melted near 22°, and there was no depression of the melting point on admixture of the two. We have now attempted to repeat the work of earlier investigators[3,7,8] who obtained a crystalline solid, melting at approximately −20°, from the reaction of peracetic acid and acetaldehyde in toluene solution at low temperatures (−30° to −40°). Following the directions of Lubarsky and Kagen,[3] we obtained crystals which melted at −5° in one experiment and 11° in another. By refinement of our purification technique (see Experimental) we were able to isolate the same crystalline product (m.p. 19–21°) which we had obtained previously.[5] No product melting as low as −20° was obtained in our work.

Establishing that the oxidation product of acetaldehyde is identical with the addition product of peracetic acid and acetaldehyde, although enlightening, does not constitute proof of structure since it is not known whether the peracetic acid adds as the peracetate anion (structure I or possibly III) or as the hydroperoxide anion[6] (structure II) or whether this addition is followed by cyclization (structure IV) or rearrangement. Furthermore, the thermal instability of this intermediate (it decomposes at 3%/hour at 0°) makes it difficult to differentiate between the possibilities by studying chemical transformations. However, by using the low-temperature cell developed by Lovell and White[10] of these laboratories, we were able to obtain infrared spectra which clearly show that structure I, α-hydroxyethyl peracetate, is the correct one for this intermediate.

Vasilyev, Terenin, and Emanuel[7] have published the only infrared data (a small part of the spectrum near 12 μ) on the addition compound of peracetic acid and acetaldehyde (m.p. −20°). On the basis of the close proximity of the peaks of the addition compound (11.8 μ) and peracetic acid (11.7 μ), they concluded that the environment of the O–O linkage was the same in both cases; *i.e.*, both compounds had the hydroperoxide group, and the addition compound therefore had the structure II. The weakness of the bands in this region, interfering absorptions of other groups such as alcohols, and the general difficulty of proper assignment of the O–O band[11] detract from the conclusions of these authors.

We have obtained infrared spectra of freshly prepared chloroform solutions of the peracetic acid–acetaldehyde addition product (m.p. 21°) at temperatures near 0°. A typical spectrum (see Fig. 1) shows a strong carbonyl band at 5.65 μ. Absorption

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[5] B. Phillips, F. C. Frostick, Jr., and P. S. Starcher, *J. Am. Chem. Soc.*, **79**, 5982 (1957).

[6] C. E. H. Bawn and J. B. Williamson, *Trans. Faraday Soc.*, **47**, 721 (1951).

[7] R. F. Vasilyev, A. N. Terenin, and N. M. Emanuel, *Bull. Acad. of Sci.* (USSR), **1956**, 385 (English Translation by Consultants Bureau, Inc.).

[8] J. D'Ans, K. Dossow, and J. Mattner, *Angew. Chem.*, **66**, 633 (1954).

[9] A. Rieche, *Angew. Chem.*, **70**, 251 (1958).

[10] C. M. Lovell and H. F. White, *Appl. Spectroscopy*, **13**, 108 (1959).

[11] L. J. Bellamy, *The Infrared Spectra of Complex Molecules*, 2nd Ed., Methuen and Co. Ltd., London, 1958, p. 120.

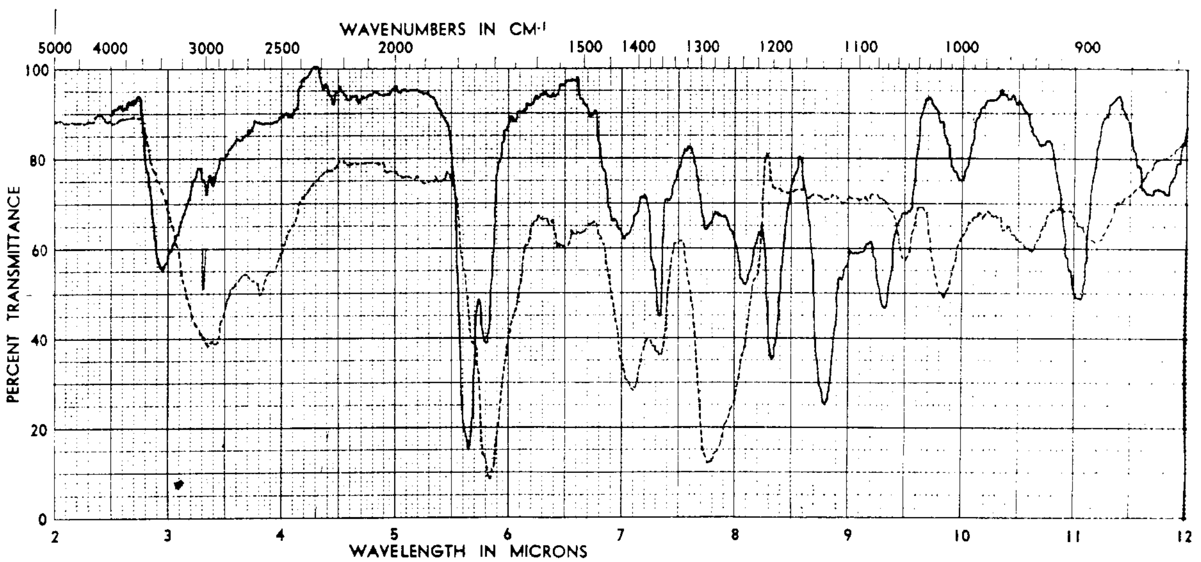
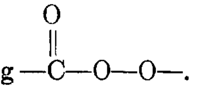
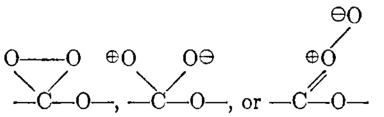


Fig. 1. Solid line, approximately 10% α-hydroxyethyl peracetate in chloroform (compensated). Dotted line, decomposed α-hydroxyethyl peracetate (compensated)

bands in this region appear in peresters,[12] peracids,[13] and as a doublet in diacyl peroxides.[14] This absorption is characteristic of the grouping  $-\overset{\overset{\displaystyle O}{\|}}{C}-O-O-$. The corresponding nonperoxidic esters and acids have carbonyl absorptions at longer wave lengths[15] (see Experimental). The presence of the 5.65 μ band eliminates structures II and IV from further consideration. Structure III is also eliminated since none of its possible forms



would be expected to absorb in this region.

Although the doublet in the carbonyl region of α-hydroxyethyl peracetate (solid line, Fig. 1) indicates another type of carbonyl (peresters form a single band), this is due to either premature decomposition to acetic acid or to a slight dissociation of I in the solvent to acetaldehyde and peracetic acid. Even by working very rapidly at low temperatures, we were not able to obtain a spectrum free of the band near 5.8 μ. Furthermore, when the chloroform solution of the addition product was allowed to stand at 0°, the 5.65 μ band slowly disappeared and the 5.8 μ band increased in intensity (acetic acid formation with corresponding drop in active oxygen content).

The rest of the spectrum in Fig. 1 (solid line) is compatible with structure I. The band at 2.8–2.9 μ is characteristic of hydrogen bonded hydroxyl. Such hydrogen bonding does not affect our proof of structure since its effect would be to shift the carbonyl absorption to longer wave lengths, *i.e.*, nearer the normal ester carbonyl.

EXPERIMENTAL

Materials. The 48.1% solution of peracetic acid in acetic acid was prepared by adding one part of reagent grade acetic acid to 3 parts of 25% peracetic acid in ethyl acetate (prepared by the oxidation of acetaldehyde[5]), removing the ethyl acetate by distillation under reduced pressure, and fractionating the resulting acetic acid–peracetic acid mixture on a 4-ft. × 30 mm., glass helix-packed column. The kettle temperature was maintained at 50° or less throughout the distillation of a 2-l. charge. Reagent grade toluene and ether and acetaldehyde which had been laboratory distilled just prior to use were employed. Spectrographic grade chloroform was used in the infrared work. *tert*-Butyl peracetate was obtained from the Lucidol Corp. as a 75% solution in benzene. *tert*-Butyl acetate was redistilled before use.

Preparation of α-hydroxyethyl peracetate in toluene solution. Following the very general directions of previous workers,[3,7,8] a mixture of 5.27 g. of 48.1% peracetic acid (0.033 mole) in acetic acid and 14.7 g. of toluene was placed in a 38 × 200-mm. test tube, stoppered with a rubber stopper fitted with a hypodermic needle and a low-temperature thermometer. The tube was cooled to −30° in a Dry Ice-acetone bath and 4.4 g. (0.1 mole) of cold acetaldehyde (−20°) was introduced through the needle with a glass syringe. After stirring slightly the solution was held at −30° for 1 hr. and then cooled to −78°. After standing 24 hr., white crystals were present. The supernatant liquid was removed by vacuum decantation through a small Pyrex glass diffuser. The crystals were washed with two 10-ml. portions of cold (−78°) ether and dried under 4 mm. pressure for 0.5 hr. while being held in a −8° bath. Melting points were determined by allowing the bath to warm slowly and observing the temperature on the thermometer submerged in the crystals. The first two preparations gave products melting at −5° and 11°. In later preparations the reaction time at −30° was shortened to 0.5 hr. and the product crystallized in 6–8 hr. at −78°, and by working rapidly during the decanting and washing steps, we were able, on the same size run as above, to obtain 3.16 g. of product (79% yield based on peracid) melting at 19.5–21°.

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[12] P. D. Bartlett, *Experientia Supplementum VII*, Birkhauser Verlag, Basel and Stuttgart, 1957, p. 175 (1957).

[13] D. Swern, L. P. Witnauer, C. R. Eddy, and W. E. Parker, *J. Am. Chem. Soc.*, **77**, 5537 (1955).

[14] Ref. 11, p. 129.

[15] Anhydrides also absorb in the region near 5.6 μ.

In no case did we obtain a product melting as low as −20°. The solutions for infrared work were obtained by dissolving the freshly prepared crystalline α-hydroxyethyl peracetate in cold chloroform.

Infrared spectra. A Baird-Atomic infrared spectrophotometer Model 4-55 was used in this work. The chloroform solution of peroxide was introduced immediately after preparation into the previously cooled low-temperature cell[10] at 0°. A variable-path length cell was used in the reference beam to compensate for the chloroform absorption. A Teflon spacer cut from 0.020 mm. sheet was used in the cell since the normal lead spacer rapidly decomposed the peroxide.

The decomposition of α-hydroxyethyl peracetate at 0° to acetic acid was followed by allowing the solution to remain in the cell and scanning the carbonyl region periodically. Spectra of several reference compounds were obtained at ambient temperature except for acetaldehyde which was obtained at 0°. The compounds and the position (in microns) of their carbonyl bands are: peracetic acid (5.68); acetic acid (5.82); *t*-butyl peracetate (5.64); *t*-butyl acetate (5.79); and acetaldehyde (5.80).

Acknowledgment. We wish to thank Professor H. H. Wasserman of Yale University for helpful discussions and criticism, and to acknowledge the technical assistance of Mr. C. M. Lovell.

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Acetals and Ketals of 1,3-Diols

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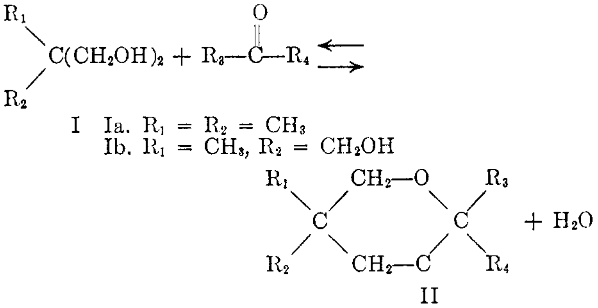
DISCUSSION

Many diacetals of pentaerythritol have been reported.[1] However, the monoacetals, monoketals, and diketals have been relatively neglected. We have investigated the synthesis of monoacetals and monoketals of pentaerythritol, and coadjutantly have prepared many diacetals and diketals of pentaerythritol and acetals and ketals of 2,2-dimethyl-propanediol-1,3 (Ia) and of 2-methyl-2-hydroxymethylpropanediol-1,3 (Ib) (Tables I, II, and III).

Acetals of 1,3-diols can be prepared by refluxing the diol with the aldehyde in the presence of an acid catalyst[1,2] even in the presence of some water.[3] With the exception of acetonals,[4] however, the corresponding ketals cannot be prepared in aqueous solution apparently because the equilibrium between I and II is unfavorable when both R_3 and R_4 are alkyl groups:



I Ia. $R_1 = R_2 = CH_3$
Ib. $R_1 = CH_3$, $R_2 = CH_2OH$

II

We have shown that most of the ketals are easily prepared, however, if the water is removed as it is formed during the reaction, by the use of an azeotropic head. Difficulty was experienced in the preparation of the ketals of benzophenone with Ia or Ib. The reactions were very slow, the yields were low, and much starting diol was recovered. Among carbonyl compounds whose ketals with Ia could not be isolated were fluorenone, benzoquinone, benzoin, benzalacetophenone, and mesityl oxide. Neither could the trisbutyral bis-Ib be formed by reaction of butyraldehyde with Ib in 3:2 molar ratio. Water evolved from all these reactions very slowly, and in part probably was formed by decomposition of the alcohol rather than by ketal formation.

Ethyl butyl ketone reacted readily with Ia or Ib to form ketals, but with pentaerythritol the reaction was very slow. As pentaerythritol is quite insoluble in benzene and ethyl butyl ketone, the reaction was tried with diethylene glycol diethyl ether as a solvent. Although pentaerythritol is quite soluble in the latter at the boiling point, the reaction was still very slow, and a pure product was not isolated.

The preparation of the monoacetals of pentaerythritol and water-insoluble aldehydes presents special problems. Very few of these monoacetals have been reported.[1] The basis of the difficulty is that the pentaerythritol is insoluble in almost all organic solvents. Therefore, if the reaction is conducted with the pentaerythritol and the aldehyde in separate phases, when the monoacetal is formed, it dissolves in the aldehyde phase and quickly reacts further to form the diacetal. Only a few such monoacetals,[1,5] have been made by heterogeneous reaction. In this work it is found that these monoacetals are more conveniently prepared in a homogeneous solution in aqueous dioxane or diethylene glycol diethyl ether (Table III). For example, monobenzal pentaerythritol was prepared in 44% yield (Method B, Experimental).

Monoketals of pentaerythritol cannot be prepared by this method because they are unstable in the presence of water. It would seem that the

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[1] E. Berlow, R. H. Barth, and J. E. Snow, *The Pentaerythritols*, Reinhold Publishing Corp., New York, 1958.

[2] (a) A. Franke and E. Gigerl, *Monatsh.*, **49**, 8 (1928); (b) R. Dvorak and T. M. Lasch, *Monatsh.*, **51**, 59 (1929); (c) R. F. Fischer and C. W. Smith, *J. Org. Chem.*, **25**, 319 (1960); (d) R. I. Meltzer, A. D. Lewis, J. Volpe, and D. M. Lustgarten, *J. Org. Chem.*, **25**, 712 (1960).

[3] (a) H. Schulz and B. Tollens, *Ber.*, **27**, 1892 (1894); (b) A. Skrabal and S. Kalpasanoff, *Ber.*, **61B**, 55 (1928).

[4] A. Skrabal and M. Zlatewa, *Z. physik. Chem.*, **119**, 305 (1926).

[5] E. Bograchov, *J. Am. Chem. Soc.*, **72**, 2268 (1950).