unity. If one expresses the efficiency of tritium labeling in terms of millicuries of incorporated activity per curie-hour of tritium exposure, the efficiency of the exchange-decarboxylation method is some 10^5 times that found when the Wilzbach method is applied to the labeling of toluene.[11]

Because of the low level of tritium activity and short exposure times, the products formed are not contaminated to any appreciable extent by high specific activity materials resulting from side reactions. In addition, the decarboxylation-distillation procedure may be expected to produce some purification. The rhodium catalyst employed in the exchange process is an excellent hydrogenation catalyst, and might be expected to accelerate hydrogenation of unsaturated linkages thus producing saturated by-products. However, the hydrogenation is ordinarily much slower than the desired exchange reaction, so that little contamination results. The tritiated *N*-methylpyrrole prepared by exchange and decarboxylation of *N*-methylpyrrole-2-carboxylic acid was examined for contamination by gas chromatography. This examination revealed the presence of a very small amount (3% or less) of a lower boiling contaminant, probably *N*-methylpyrrolidine. This contaminant can be readily removed by chromatographic processes. Incidentally, the problem of hydrogenation of unsaturated linkages is also present when the Wilzbach method is employed.[5]

While the method of labeling which has been described is not as general as that of Wilzbach, it should be applicable to any compound containing a carboxyl group which can be readily decarboxylated. It has the advantage of employing low activities of tritium and short exposure times and producing products of high purity labeled in specific positions.

A similar method has been used for producing nicotinic acid-2-*t*-through decarboxylation of tritiated quinolinic acid.[12] However, the latter compound was prepared through exchange with tritium oxide rather than the readily available tritium gas.

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Preparation of *trans*-Stilbene from Benzoin

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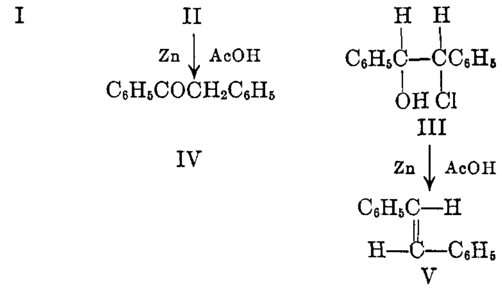
A procedure for the preparation of *trans*-stilbene developed by one of us[1] calls for reaction of benzoin with thionyl chloride to produce desyl chloride (II), reduction with sodium borohydride to give a product rich in the *erythro* chlorohydrin III, and reaction with zinc dust and acetic acid. The two reduction steps are run consecutively in the same ethanol solution. If deteriorated sodium borohydride is used (University of Illinois), the low-melting product is desoxybenzoin (IV). At the Massachusetts Institute of Technology most members of the class obtained *trans*-stilbene but a few encountered desoxybenzoin. After trying all conceivable variations in the second and third steps to no avail, the author of the manual considered the possibility for variable interpretation of the following direction: "Place four grams of benzoin (crushed to a powder) in a one hundred-milliliter round-bottomed flask, cover it with four milliliters of thionyl chloride, warm gently on the steam bath (hood) . . . . " The comma after "thionyl chloride" represents a pause in operation, as in reading. The pause is ordinarily not more than a second or two, but it could be long, as over the lunch hour or overnight. Trial indeed showed that if the mixture of reagents is let stand at room temperature until reaction is complete and the subsequent steps are then applied, the final product that crystallizes from ethanol is desoxybenzoin. The yield is low; a major product, retained in the mother liquor, is *meso*-hydrobenzoin. For avoidance of trouble at this stage, and to insure removal of all excess thionyl chloride which otherwise affords sulfur in the next step, the present procedure is as follows: "Put four grams of benzoin into a tared one hundred-milliliter flask and mount the



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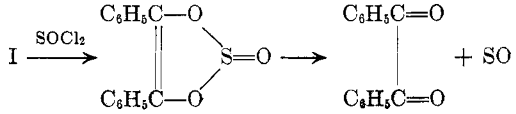
[11] H. J. Ache, W. Herr, and A. Theimann, Proceedings of the Symposium on the Detection and Use of Tritium in the Physical and Biological Sciences, Vienna, Austria, 1961, paper 10, in press.

[12] R. F. Dawson, D. R. Christman, A. D'Adamo, M. L. Solt, and A. P. Wolf, *J. Am. Chem. Soc.*, **82**, 2628 (1960). *Cf.* A. P. Holemann and K. Clusius, *Ber.*, **70**, 819 (1937).

[1] L. F. Fieser, "Experiments in Organic Chemistry," 3rd ed., revised, D. C. Heath, 1957, pp. 178–180. For an interpretation of the stereochemistry, see L. F. Fieser and M. Fieser, "Advanced Organic Chemistry," Reinhold Publishing Corp., 1961, pp. 165–170.

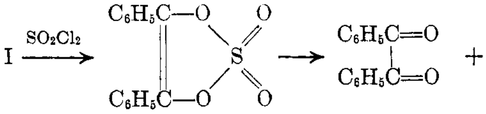
flask on the steam bath under a reflux condenser (hood). Heat the flask containing the benzoin and then pour in four milliliters of thionyl chloride through the condenser. Reflux for five minutes, then remove the condenser and heat for five minutes to drive off gases and thionyl chloride. Then connect the flask with a rubber stopper to the suction pump and heat on the steam bath to constant weight (four grams of benzoin gives four and three tenths grams of desyl chloride)."

A further study of the reaction between benzoin (one mole) and thionyl chloride (three moles) at 20° and at 0° showed that the reaction products are desyl chloride, benzil, and sulfur. We postulate that the initial product is the cyclic endiol sulfite VI, which decomposes to benzil and sulfur



VI

monoxide. This oxide is known to yield sulfur by disproportionation: $2SO \rightleftharpoons SO_2 + {}^1/_2\ S_2$.[2] Borohydride reduction of VI to desoxybenzoin is understandable. Attempts to isolate the intermediate were unsuccessful, as were attempts to isolate the sulfate ester VII from benzoin and sulfuryl chloride.



VII

However, the transient formation of VII is indicated by the observation that when a mixture of benzoin (one mole) and sulfuryl chloride (three moles) was let stand at room temperature, benzil and sulfur dioxide were formed in equivalent amounts and in high yield. That benzil is produced in higher yield in this reaction than in the reaction with thionyl chloride is perhaps due to the greater stability of the gaseous product.

Further evidence in support of the structures postulated including isolation of the crystalline 2,2′-4,4′,6,6′-hexamethyl derivative of VI from reaction of the known endiol[3] with thionyl chloride and pyridine in methylene chloride at −20°, will be presented by the junior author in candidacy for a degree in Japan.

Experimental

Reaction of Benzoin with Thionyl Chloride.—A mixture of 2 g. of benzoin and 2 ml. of thionyl chloride when let stand at 0° for 12 hr. afforded a yellow solution, and evacuation at the water pump afforded a viscous brown oil which solidified on standing. The infrared spectrum showed bands at 1718 cm.$^{-1}$ (desyl chloride) and 1686 cm.$^{-1}$ (benzil). Chromatography on alumina afforded 1.18 g. of desyl chloride, m.p. 68°, 0.71 g. (35%) of benzil, m.p. 96°, and a trace of sulfur.

For quantitative determination of both benzil and the gaseous products, 320.3 mg. of benzoin was placed in a small Claisen flask cooled in an ice bath and supplied with a gas inlet tube. The sidearm was connected through a Dry Ice–acetone trap (to catch thionyl chloride) to two absorption tubes containing 1 *N* sodium hydroxide. The system was flushed with nitrogen and then stopcocks at the ends of the system were closed and 0.45 ml. of thionyl chloride was added to the benzoin. After 12 hr., a slow stream of nitrogen was passed through the system for 3 hr. and then the system was evacuated twice to sweep gas dissolved in the reaction mixture into the absorption tubes. The residual syrup was analyzed spectrophotometrically using the benzil band at 11.52 μ and found to contain 125 mg. (39%) of the diketone. The solution in each absorption tube was neutralized with 1 *N* hydrochloric acid at 0° and titrated iodimetrically. Since the total iodine consumption was 37×10^{-4} equiv., whereas the benzil produced was only 5.9×10^{-4} equiv., considerable thionyl chloride must have been carried over into the absorption tubes. A blank run with benzil in place of benzoin showed this to be the case and afforded 22×10^{-4} equiv. of iodine. The difference, 15×10^{-4} equiv., is in the order of magnitude of the benzil formed.

In a run conducted with benzoin as before but at 20° (12 hr.), the yield of benzil was 29%.

Reaction of Benzoin with Sulfuryl Chloride.—This reaction presents a simpler case than that with thionyl chloride because the sole gaseous product is sulfur dioxide and because reagent swept into the absorption tubes is converted into sodium sulfate. In an experiment conducted like that described above, 226.5 mg. of benzoin treated at 0° with 0.4 ml. of sulfuryl chloride afforded 205 mg. (95%) of benzil, and 1.6×10^{-3} mole (94%) of sulfur dioxide.

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[2] H. Zeise, *Z. Physik. Chem.*, **B51**, 120 (1942).

[3] R. C. Fuson, C. H. McKeever, and J. Corse, *J. Am. Chem. Soc.*, **62**, 600 (1940).

DL- and L-Threonine *p*-Toluenesulfonate Benzyl Ester[1]

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For a projected synthesis of the threonine containing chromopeptide actinomycin D, which has carcinostatic activity,[2] we required L- and/or DL-threonine benzyl ester. Since the problem of the synthesis of actinomycins has been solved in principle by the recent total synthesis of actinomycin C_3,[3] which is very closely related to actinomycin D, work on the project has been discontinued. We wish to report here the preparation and properties of DL- and L-threonine *p*-toluenesulfonate benzyl ester since these compounds might be useful for the synthesis of threonine peptides. Although DL-serine benzenesulfonate benzyl ester can be obtained readily as a crystalline solid by the

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[1] Supported by a grant (C-2571) from the National Cancer Institute, U. S. Public Health Service.

[2] S. Farber, *Am. J. Path.*, **31**, 582 (1955).

[3] H. Brockmann, *Angew. Chem.*, **72**, 939 (1960).