

shielding of the ethynyl group. The *ortho* hydrogen, however, is in very close proximity of the axial hydroxyl group and it seems likely that the downfield shift of the *ortho* hydrogen in this isomer results from a deshielding effect of the axial hydroxyl group, while the effect in the other isomer results from a deshielding of the *ortho* hydrogen by the axial ethynyl group. The long-range deshielding effect of the hydroxyl group is a recognized phenomenon.<sup>14-16</sup> This interpretation was tested by measuring the n.m.r. spectra of the hydrogenation product of the two ethynyl isomers and found to be correct. If the interpretation is correct the downfield shift of the *ortho* hydrogen should persist in 1-ethyl-*cis*-2-*o*-tolylcyclohexanol (ethyl group equatorial) and disappear in 1-ethyl-*trans*-2-*o*-tolylcyclohexanol (ethyl group *cis* to the tolyl group). Curves A and B of Fig. 1 show that this is exactly what takes place. Actually the paramagnetic shift of the *ortho* hydrogen is greater with the equatorial ethyl group than with the equatorial ethynyl group. The signal of the hydrogen on C-2 of 1-ethyl-*cis*-2-*o*-tolylcyclohexanol gives the typical quartet with *a,a* splitting of 11.2 c.p.s. and *a,e* splitting of 3.5 c.p.s. Indicating the chair conformation with the aromatic group in equatorial orientation as expected, while the signal of the C-2 hydrogen of 1-ethyl-*trans*-2-*o*-tolylcyclohexanol gives a broad unresolved multiplet. This could result from an equilibrium between the two possible chair conformations in this isomer where the tolyl and ethyl groups are *cis* to each other; but it could also possibly result from the difference in long-range shielding effects of the axial ethyl group compared to the axial ethynyl group on the axial hydrogen on C-3. This point will be clarified by the preparation of selectively deuterated compounds.

### Experimental

The separation of the liquid mixtures of 1-ethynyl-2-tolylcyclohexanols<sup>2</sup> into their *cis* and *trans* components was accomplished with a Beckman GC-2 gas chromatograph using a 10 ft.

(14) J. N. Shoolerey and M. T. Rogers, *J. Am. Chem. Soc.*, **80**, 5121 (1958).

(15) W. H. Tallent, *J. Org. Chem.*, **27**, 2968 (1962).

(16) Y. Kawazoe, Y. Sato, M. Natsume, H. Hasegawa, T. Okamoto, and K. Tsuda, *Chem. Pharm. Bull., Japan*, **10**, 338 (1962).

× 5/8 in. column packed with 18% Dow Corning Silicone QF-1 on acid-washed Chromosorb W<sup>17</sup> at 160°.

**1-Ethyl-*cis*-2-*o*-tolylcyclohexanol and 1-Ethyl-*trans*-2-*o*-tolylcyclohexanol.**—These compounds were obtained by catalytic hydrogenation of the corresponding 1-ethynyl-2-*o*-tolylcyclohexanols in ethyl acetate using 10% palladium on carbon under 20 pounds pressure. The calculated amount of hydrogen was picked up rapidly. The products were purified by gas chromatography at 160° using the same column used to separate the ethynyl compounds. The products were also obtained by reduction of the mixture of ethynyl compounds and subsequent separation of the isomers by gas chromatography with a 10-ft. column of 18% Carbowax 20M on acid-washed Chromosorb W at 196°.

*Anal.* Calcd. for C<sub>15</sub>H<sub>22</sub>O: C, 82.51; H, 10.16. Found for the *cis* isomer: C, 82.64; H, 10.21. Found for the *trans* isomer: C, 82.53; H, 10.29.

TABLE II  
PHYSICAL CONSTANTS AND ANALYSES<sup>a</sup>

Compound	M.p., °C. <sup>b</sup>	—Found, %—	
		C	H
1-Ethynyl- <i>cis</i> -2- <i>p</i> -tolylcyclohexanol	36-37	83.95	8.16
1-Ethynyl- <i>trans</i> -2- <i>p</i> -tolylcyclohexanol	65.5-66.5	83.95	8.73
1-Ethynyl- <i>cis</i> -2- <i>m</i> -tolylcyclohexanol	56-56.5	84.03	8.39
1-Ethynyl- <i>trans</i> -2- <i>m</i> -tolylcyclohexanol	°	84.06	8.23
1-Ethynyl- <i>trans</i> -2- <i>o</i> -tolylcyclohexanol	56-57	84.29	8.40
1-Ethynyl- <i>cis</i> -2- <i>o</i> -tolylcyclohexanol	81-82	83.91	8.50

<sup>a</sup> Calcd. for C<sub>15</sub>H<sub>18</sub>O: C, 84.07; H, 8.47. <sup>b</sup> Melting points were determined with a Kofler micro hot stage. <sup>c</sup> This compound was obtained as a viscous, colorless liquid.

**1-Ethynyl-*trans*-4-*t*-butylcyclohexanol and 1-Ethynyl-*cis*-4-*t*-butylcyclohexanol.**—These two isomers were obtained by the method of Hennion and O'Shea.<sup>18</sup> The configurations assigned by these authors on the basis of kinetics of saponification of the *p*-nitrobenzoate esters are in agreement with the observed chemical shifts of the hydroxyl protons of these two isomers when compared to the relative chemical shifts of axial and equatorial hydroxyl protons of other cyclohexanols (Table I and ref. 3 and 4). Because of the variability in the chemical shifts of hydroxyl protons this observation does not constitute proof of conformation.

(17) Wilkens Instrument and Research, Inc., Walnut Creek, Calif.

(18) G. F. Hennion and F. X. O'Shea, *J. Am. Chem. Soc.*, **80**, 614 (1958).

## 4-(*p*-Tolyl)-1-pentanol in Douglas Fir Pulping Products<sup>1</sup>

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An optically active alcohol has been isolated from the product of pulping Douglas fir *via* the kraft process. This has been identified by degradation and synthesis as 4S-4-(*p*-tolyl)-1-pentanol. It is suggested that this alcohol is formed during the pulping process from  $\gamma$ -curcumene, a terpene not previously identified in Douglas-fir extractives.

Among the organic products derived from the pulping of wood of the Douglas fir, *Pseudotsuga menziesii*, [Mirb. (Franco)] by the kraft process are some with a considerable biological activity. In particular the toxicity of the by-product toward a number of species

of fish has been thoroughly established. Recent work on this campus<sup>2</sup> established that one or more of these toxic substances could be steam distilled. It occurred to us that some of the biologically active materials could be related chemically to the furocoumarin fish

(1) This project was supported by a research grant, no. WPOO79-5 from the Division of Water Supply and Pollution Control, Public Health Service.

(2) Robert A. McHugh, "Preliminary report on a study of the factors responsible for the toxicity of waste from a modern kraft pulp mill," Oregon State University, 1954.

poisons such as xanthotoxin, bergapten, imperatorin, and the more complex derivatives like rotenone.<sup>3</sup> The formation of coumarins or benzofurans or both from the substituted  $\gamma$ -phenylpropyl groupings present in lignin<sup>4</sup> would not be surprising in an aqueous polysulfide medium as is present in kraft pulping liquors. Work was initiated, therefore, aimed at the isolation and identification of the biologically active components in the by-products of the kraft pulping process.

A sample of the by-product materials from a kraft cook on Douglas fir was steam distilled and the organic materials in the distillate extracted with ether. There was obtained 63.4 g. of dark colored liquid which was separated into three fractions by distillation *in vacuo*. The fraction boiling from 56–95° (0.3 mm.) was chromatographed on silicic acid and the major component of this fraction, 7.31 g. of colorless oil, exhibited a strong toxicity toward fish. This component, labeled II-2, was shown to be uniform and attention was directed toward ascertaining its structure.

The infrared spectrum of II-2 showed the presence of a hydroxyl group (3400  $\text{cm}^{-1}$ ) and a benzene ring (1500  $\text{cm}^{-1}$ ). Although a small peak at 1625  $\text{cm}^{-1}$  and bands at 984 and 895  $\text{cm}^{-1}$  suggested the possible presence of an olefinic double bond, the liquid failed to add hydrogen and did not react with perbenzoic acid. The spectrum suggested a primary alcohol and a 3,5-dinitrobenzoate formed readily. The analysis of both the original oil and the derivative were in good accord with the formula  $\text{C}_{12}\text{H}_{18}\text{O}$  for the alcohol. The ultraviolet spectrum was not appreciably altered by the addition of alcoholic sodium hydroxide and the substance was therefore an alcohol and not a phenol.

The pattern of bands between 1700 and 2000  $\text{cm}^{-1}$  and the band at 812  $\text{cm}^{-1}$  suggested that the benzene ring was *para* disubstituted. This was confirmed by the formation of terephthalic acid *via* oxidation with alkaline permanganate. In order to ascertain the partitioning of the carbon atoms between the two chains a differential oxidation with nitric acid<sup>5</sup> was carried out. Paper chromatography showed the presence of *p*-toluic acid, malonic acid, and oxalic acid in the oxidation product. A crude sample of *p*-toluic acid was isolated which showed an infrared spectrum identical with that of an authentic specimen. Amongst the optically active alcohols to be considered at this point 4-(*p*-tolyl)-1-pentanol provided the most reasonable structure for the following reasons.

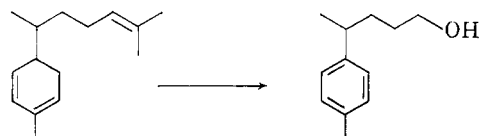
It seems clear that the alcohol could not arise from lignin, and since the optical activity necessitates a natural source a terpene precursor seemed likely. This structure conforms to the isoprene rule. It also provides a ready rationale for the formation of malonic acid during the nitric acid oxidation. Finally a survey of the literature revealed that 4-(*p*-tolyl)-1-pentanol is known<sup>6</sup> and forms a 3,5-dinitrobenzoate which melts at the same temperature. It seemed appropriate, therefore, to prepare a comparison sample.

Racemic 4-(*p*-tolyl)-1-pentanol was prepared from 3-(toluoyl)propionic acid by treatment with methyl Grignard and reduction of the  $\gamma$ -(*p*-tolyl)- $\gamma$ -valerolactone to 4-(*p*-tolyl)pentanoic acid by the Clemmensen method. This acid was reduced to the required alcohol by lithium aluminum hydride. The alcohol obtained from the hydride reduction showed an infrared spectrum identical with that of the unknown alcohol and the 3,5-dinitrobenzoates had the same melting point. Therefore, II-2 is optically active 4-(*p*-tolyl)-1-pentanol, a substance not previously known to be formed during the kraft process.

Calculations using the conformational asymmetry model<sup>7</sup> predict that the S configuration<sup>8</sup> of 4-phenyl-1-pentanol should have a dextro rotation,  $[\phi] = +40^\circ$ . The molecular rotation of the 4-(*p*-tolyl)-1-pentanol isolated is  $+67^\circ$  which suggests that it has an S configuration and is of high optical purity.

As was noted earlier the lack of structural relationship between this alcohol and the typical  $\gamma$ -phenylpropyl skeleton of lignin breakdown products, and the direct relation to a sesquiterpene skeleton makes a terpene precursor seem reasonable. The sesquiterpene hydrocarbons, bisabolene, zingerberene, and the curcumenes,<sup>9</sup> all have the proper carbon skeleton to be precursors of this alcohol. While none can be eliminated from consideration, only bisabolene<sup>10</sup> and  $\gamma$ -curcumene<sup>11</sup> appear to have been isolated from conifers. Though bisabolene is biologically the more reasonable parent due to its wide distribution in nature, the great ease of conversion of  $\gamma$ -curcumene to an aromatic compound<sup>11</sup> makes it chemically the more appropriate ancestor.

The conditions of the kraft reaction involve a basic, aqueous sulfide medium which resemble those of the well investigated Willgerodt reaction,<sup>12</sup> except that a lower sulfur content is present under kraft conditions. Both oxidation and reduction of the organic substrate can occur during the Willgerodt reaction, and indeed oxidative cleavage of an olefinic double bond has been observed.<sup>13</sup> Willgerodt media low in sulfur content have been found<sup>12</sup> to lead to partial oxidation so that aldehydes or ketones rather than acid derivatives are the products, and reduction of carbonyl groups by inorganic sulfides<sup>14</sup> has been noted. Thus all of the reactions required to convert  $\gamma$ -curcumene to 4-(*p*-tolyl)-



1-pentanol have been shown to occur at elevated temperatures in basic polysulfide media. No previous evidence for the presence of a sesquiterpene hydrocarbon of this skeleton in Douglas fir extractives has come to the attention of the authors.

(3) For a brief review of these substances see N. Campbell in Rodd, "Chemistry of Carbon Compounds," Vol. IV B, Elsevier, Amsterdam, 1959, pp. 883–887.

(4) F. E. Brauns and D. A. Brauns, "The Chemistry of Lignin Supplemental Volume Covering the Literature for the Years 1949–1958," Academic Press, New York, N. Y., 1960, pp. 616–629.

(5) L. N. Ferguson and A. I. Wims, *J. Org. Chem.*, **25**, 668 (1960).

(6) F. D. Carter, J. L. Simonsen, and M. O. Williams, *J. Chem. Soc.*, 451 (1940).

(7) J. M. Brewster, *J. Am. Chem. Soc.*, **81**, 5475 (1959).

(8) R. S. Cahn, C. K. Ingold, and V. Prelog, *Experientia*, **12**, 81 (1956).

(9) J. Simonsen and D. H. R. Barton, "The Terpenes," Cambridge University Press, Cambridge, Mass., 1952, Vol. III, pp. 9–25.

(10) L. Ruzicka and E. Capato, *Helv. Chim. Acta*, **8**, 263 (1925).

(11) R. D. Batt and S. N. Slater, *J. Chem. Soc.*, 838 (1949).

(12) W. A. Pryor, "Mechanisms of Sulfur Reactions," McGraw-Hill Book Co., Inc., New York, N. Y., 1962, pp. 127–139.

(13) W. G. Toland, D. L. Hagmann, J. B. Wilkes, and F. J. Brutschy, *J. Am. Chem. Soc.*, **80**, 5423 (1958).

(14) E. Baumann and E. Fromm, *Ber.*, **28**, 907 (1895).

It is interesting that 4-(*p*-tolyl)-1-pentanol is quite toxic to fish<sup>15</sup> but since the percent of the total toxicity accounted for by this alcohol is lower than its weight percent in the initial sample, more toxic substances are present in the as yet uninvestigated residue. The alcohol also shows inhibitory activity toward the cytochrome-oxidase system *in vitro* which rivals that of cyanide ion. Such high biological activity seems unusual for a molecule of this structure.

### Experimental

**Sample Preparation.**—Raw material for study was obtained from a kraft pulp mill pulping only Douglas fir chips, and producing unbleached pulp. Samples totalling 130 gal. of condensate from the low vacuum stage of the weak black liquor evaporator were collected at random intervals during the summer of 1959. This liquor containing the steam distilled by-products of the kraft cook was distilled under reduced pressure at 85–90° in 5-gal. batches. Each batch was reduced to about 350-ml. residue which was discarded. The distillate was extracted with ether for 24 hr. in a liquid-liquid extractor. The ether extract was dried over anhydrous magnesium sulfate and the ether removed *via* distillation using a Fenske column. The residue consisted of 63.4 g. of viscous dark oil with a characteristic odor. This material was distilled *in vacuo* using a simple Claisen head. Three fractions were obtained: I, b.p. 30–56° (0.3 mm.), 5.4 g. of light yellow mobile oil; II, b.p. 56–95° (0.3 mm.), 11.0 g. of light yellow oil; and III, residue 46.5 g. of dark viscous oil. An attempt to distil a portion of the residue by molecular distillation resulted in decomposition.

**Fraction I.**—Preparative gas chromatography using an 8.5 ft. × 0.5 in. column of 20% Reoplex 400 on Celite at 170° permitted separation of fraction I into three portions: I-1, 40 mg. of colorless liquid; I-2, 1.14 g. of light tan liquid; and I-3, 4.25 g. of light brown liquid. A chromatogram of I-1 on a 14 ft. × 1/8 in. column of 10% Carbowax 20M on firebrick at 172° using helium as carrier gas showed eighteen peaks. Fraction I-2 was rechromatographed on the original preparative column and two fractions, I-2a, 620 mg. of dark brown oil, and I-2b, 500 mg. of a light yellow oil, were collected.

Fraction I-2a was chromatographed on a 14 ft. × 1/8 in. column packed with 10% Carbowax 20M on firebrick at 133° showing eighteen peaks. This fraction was then chromatographed on a 12 ft. × 1/8 in. column packed with 10% Craig polyester on firebrick at 108°, showing fifteen peaks. The areas under the various peaks were used to provide an arbitrary interrelationship between the peaks on the two columns through only about ten peaks could be reasonably identified in this way. Mixture of fraction I-2a with anisole,  $\beta$ -pinene, *p*-cymene, citronellol, terpinolene, linalool, limonene, terpinene, methone, and menthofuran were run through both columns. When the related peaks on both columns were enlarged by addition of the same component, that component was considered to be satisfactorily identified. Thus limonene, terpinene, *p*-cymene, and anisole were found to be present.

Fraction I-2b was uniform to gas chromatography on the above columns. The liquid had the following properties: mol. wt., 235 (osmometer),  $\nu = 3400, 1725, 1680, \lambda_{\max} 238$  (ca. 27,000), 280 (ca. 5000). A solution containing 43 mg. of I-2b in ethanol was mixed with 1.5 ml. of a solution of 2,4-dinitrophenylhydrazine in diglyme. Two drops of hydrochloric acid were added and the solution allowed to stand 24 hr. The deep red precipitate was recrystallized from benzene and 2 mg. of orange crystals, m.p. > 300° were isolated.

Fraction I-3 was uniform to gas chromatographic tests. It was distilled *in vacuo* giving 4.0 g. of colorless oil, b.p. 95° (0.3 mm.),  $\nu = 3480, 3050, 1610, 1605, 1513, \text{ and } 750 \text{ cm.}^{-1}$ . One gram of I-3 was mixed with 0.7 g. of benzoyl chloride and the mixture boiled for 5 min. The mixture was poured onto ice and the residue triturated with 5% sodium carbonate solution. The solid residue was recrystallized from ethanol, m.p. 58°. A mixture with an authentic sample of guaicol benzoate melted at 58°.

**Fraction II.**—Elution chromatography of 6.98 g. of fraction II on 200 g. of predried silicic acid using 2 l. of ligroin, 2 l. of benzene, 1 l. of carbon tetrachloride, 1 l. of chloroform, 1 l. of ether, and 1 l. of methanol in that order as eluants separated five fractions as indicated by a plot of weight of material per tube against tube number. These were combined as the following fractions: II-1, 500 mg. of colorless liquid, II-2, 4.25 g. of light brown oil, II-3, 308 mg. of a dark oil, II-4, 263 mg. of a dark oil and II-5, 850 mg. of a viscous brown liquid.

Fractions II-1, II-3, and II-4 were shown by gas chromatography to contain 16, 17, and 16 components, respectively. These were not investigated further.

**Fraction II-2.**—was purified by chromatography on activity III (Brockman) alumina and the main fraction eluted in benzene. This was distilled to give 2.6 g. of a clear liquid, b.p. 72–74° (0.1 mm.),  $n_D^{20} 1.5051, d_4^{20} 0.9635; \lambda_{\max} 237, 259, 265; \nu = 3400, 2900, 1860 \text{ w, } 1622, 1500 \text{ s, } 1050, 984, 895, 812, \text{ and } 720 \text{ cm.}^{-1}; [\alpha]_D^{25} + 38.1$  (95% ethanol, 4.64 mg./ml.). This substance did not add hydrogen or react with perbenzoic acid.

*Anal.* Calcd. for C<sub>12</sub>H<sub>18</sub>O: C, 80.85; H, 10.18. Found: C, 80.45, 80.74; H, 10.08, 9.98.

**II-2 3,5-Dinitrobenzoate.**—A solution containing 100 mg. of II-2 and 200 mg. of 3,5-dinitrobenzoyl chloride in 0.3 ml. of pyridine was warmed on a steam bath for 10 min. The solution was poured into 4 ml. of water, the insoluble residue washed with 2% sodium carbonate, and the solid material recrystallized from ethanol. Thus 50 mg. of bright yellow crystals, m.p. 78°, was obtained.

*Anal.* Calcd. for C<sub>15</sub>H<sub>20</sub>N<sub>2</sub>O<sub>6</sub>: C, 61.28; H, 5.14. Found: C, 61.19, 61.37; H, 5.37, 5.14.

**Oxidation of II-2.**—A solution containing 37.8 mg. of II-2 and 250 mg. of potassium permanganate in 7.5 ml. of water was heated on a boiling water bath for 6 hr. The manganese dioxide was removed by filtration, the solution acidified with hydrochloric acid, and extracted with ether. The ether extracts were dried over anhydrous magnesium sulfate. Evaporation of the ether gave 28.2 mg. of white crystals which sublimed without melting at 250°. The infrared spectrum (KBr pellet) was identical with that of an authentic specimen of terephthalic acid.

A solution of 77.5 mg. of II-2 in 1.5 ml. of 3.5 N nitric acid was heated under reflux for 12 hr. Sufficient 1 N sodium hydroxide was added to dissolve the precipitate, a small amount of powdered zinc added and the mixture heated for 1 hr. A portion of the solution was distilled to remove reduced nitration products, and the zinc removed from the residue. The aqueous solution was acidified, extracted with ether and the ether extracts dried. Paper chromatography of the extracts on Whatman no. 4 paper using ethanol-ammonia-water (80:4:16) showed four spots, *R<sub>f</sub>* 0.73, 0.44, 0.26, and 0.00. Under the same conditions the following *R<sub>f</sub>* values were observed: *p*-toluic acid 0.72, acetic acid 0.43, malonic acid 0.25, and oxalic acid 0.00. The ether was evaporated from the extracts and 29.9 mg. of white crystals, m.p. 158–166°, were recovered. The infrared spectrum was nearly identical with that of *p*-toluic acid.

**Fraction II-5.**—gave after standing in the cold a crystalline magna. After recrystallization from benzene-ligroin, 50 mg. of white crystals, m.p. 90–92°, were obtained. These showed infrared absorption at 3400, 2940, 2880, 1625 w, 1470, 1445, 1420, 1380, 1170, 1125, 1010, 987, 947, 900 and 835 cm.<sup>-1</sup>. II-5 decolorized potassium permanganate and bromine water but did not give a color with ferric chloride.

**3,5-Dinitrobenzoate of II-5.**—was prepared as described above for II-2. Recrystallization from ethanol gave 60 mg. of pale pink crystals, m.p. 170–171°,  $\lambda_{\max} 230 \text{ m}\mu$  ( $E_{1\%}^{1\text{cm}}$  774). The melting point suggests a di-3,5-dinitrobenzoate and, using  $\lambda_{\max} 230 \text{ m}\mu$  ( $\epsilon$  45,000) for the average for such derivatives, the mol. wt. of II-5 is estimated at 190 ± 20. Analytical data were unsatisfactory.

**$\gamma$ -(*p*-Tolyl)- $\gamma$ -valerolactone.**—To a solution containing 0.25 mole of methyl Grignard reagent was added slowly a solution of 23.6 g. (0.123 mole) of 3-(*p*-toluoyl)propionic acid<sup>16</sup> in ether. The reaction mixture was heated at reflux for 2 hr., then decomposed with cold dilute sulfuric acid. The ether layer was separated, washed with dilute sodium hydroxide, and dried. After evaporation of the ether the lactone was distilled, b.p. 98° (0.05

(15) The authors are indebted to Dr. Charles Warren of the Fish and Game Department, Oregon State University, for the biological toxicity determination which will be reported in detail elsewhere.

(16) E. de B. Barnett and F. G. Saunders, *J. Chem. Soc.*, 434 (1933).

mm.), 7 g. (40% based on acid used),  $\nu = 1775 \text{ cm.}^{-1}$ . A melting point of  $56^\circ$  has been reported<sup>17</sup> for this lactone.

**4-(*p*-Tolyl)pentanoic Acid.**—The previous lactone was reduced according to the procedure of Martin.<sup>18</sup> After 22 hr. the toluene layer was separated and extracted with dilute sodium hydroxide. The basic layer was acidified with hydrochloric acid and extracted with ether. The ether extracts were dried and the product distilled, b.p.  $115^\circ$  (1.5 mm.), 2.7 g. (38%). Boiling points of  $173^\circ$  (9 mm.)<sup>17</sup> and  $180^\circ$  (14 mm.)<sup>6</sup> have been reported.

**4-(*p*-Tolyl)-1-pentanol.**—The above acid was esterified with ethanol and hydrochloric acid. The ester, b.p.  $144^\circ$  (9 mm.),<sup>6,17</sup>

was obtained as a colorless oil in 78% yield. A solution containing 2.3 g. of the ester in ether was added dropwise to a solution containing 0.47 g. of lithium aluminum hydride and the solution stirred at room temperature for 15 min. Excess hydride was destroyed with moist ether. The product was distilled *in vacuo*, b.p.  $72\text{--}74^\circ$  (0.1 mm.), 1.28 g. (62%). Simonsen<sup>4</sup> reports a boiling point of  $151^\circ$  (16 mm.) for this alcohol. Its infrared spectrum was identical with that of II-2 and its 3,5-dinitrobenzoate melts at  $78^\circ$  (reported<sup>6</sup> m.p.  $80^\circ$ ).

**Infrared Spectra.**—Infrared spectra were carried out unless otherwise specified on neat liquids using a Perkin-Elmer Model 21 spectrometer.

**Gas Chromatography.**—A Model 154C Perkin-Elmer vapor fractometer was used with helium as the carrier gas under the conditions indicated in each case.

(17) H. Rupe and A. Steinback, *Ber.*, **44**, 584 (1911).

(18) E. L. Martin, *J. Am. Chem. Soc.*, **58**, 1438 (1936).

## The meso and Racemic Forms of 2,4-Pentanediol and Certain of Their Derivatives

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The meso and racemic forms of 2,4-pentanediol have been separated from their mixture *via* fractional distillation of their cyclic sulfite esters, and their structures identified through their proton resonance spectra. The separated diols have been converted to diacetates, bis-3,5-dinitrobenzoates, dichlorides, and dibromides of corresponding structural symmetry and the isomeric pairs characterized. The reduction of acetylacetone by sodium-ethanol, nickel-hydrogen, and sodium borohydride yielded the meso and racemic 2,4-pentanediols in the ratios 9:11, 11:9, and 2:1, respectively.

The meso and racemic forms of 2,4-pentanediol and their derivatives are of topical interest as model systems for spectroscopic and chemical studies relating to polymers.<sup>1-6</sup> This paper discusses a convenient preparation for the isomeric diols, and their conversion to dihalides and other derivatives.

Previously reported separations of meso and racemic forms in 2,4-disubstituted pentane systems are as follows. The sodium hydroxide complexes of the diol cyclic borate esters have been separated in aqueous solution by paper ionophoresis<sup>7</sup> and by chromatography on the borate form of an anion-exchange resin<sup>3</sup>; the diol mono-*p*-bromobenzenesulfonate esters have been separated by solution chromatography on alumina.<sup>8</sup> The dichlorides have been separated in the vapor phase on a dioctyl phthalate column<sup>5</sup> and the diamines were separated long ago *via* crystallization of their acetyl derivatives.<sup>9</sup> Apart from the last system, the above separations are suitable only for small quantities unless very large sized equipment is used. It was, therefore, our aim to develop a simple distillation method for large-scale separation of the diol isomers in a pure state (*via* an ester derivative), using chromatography only as a method of analysis for the isomers. Then, the further goal was to study methods for converting each pure

form of the diol to some other useful 2,4-disubstituted pentane derivatives, without loss of isomeric purity.

### Results and Discussion

**Separation and Characterization of meso and Racemic 2,4-Pentanediol.**—An experimental review of various methods of reduction of acetylacetone—a readily available starting material—showed that a most straightforward procedure for obtaining a high yield of good-quality diol mixture could be worked out using sodium borohydride, which we recommend in preference to other methods even though it gives an isomer ratio somewhat removed from 1:1 (see Experimental).

A separation of the isomeric diols *via* fractional distillation of their cyclic sulfite esters<sup>10</sup> was found to work quite successfully. Thus, the conversion of the diol mixture to a cyclic sulfite mixture through thionyl chloride was straightforward, requiring only the simplest apparatus; and direct fractionation of the reaction mixture without elaborate work-up was satisfactory. The meso and racemic cyclic sulfites, the b.p. of which differ by only  $10^\circ$  at 12 mm., apparently form a sufficiently non ideal boiling mixture for a clean separation to be achieved in a modestly efficient fractionating column (see Experimental). The hydrolysis of the individual cyclic sulfite isomers back to diols with aqueous sodium hydroxide was straightforward, and this type of process is known to occur by sulfur-oxygen bond fission, *i.e.*, without the possibility of change of configuration.<sup>11,12</sup> The over-all yields of pure diol

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