sym-**Divinylethylene Carbonate (II).**—A mixture of 57 g. (0.5 mole) of 1,5-hexadiene-3,4-diol, 71 g. (0.6 mole) of diethyl carbonate and 0.2 g. of anhydrous potassium carbonate was slowly heated to 110°. At this temperature reaction occurred and ethyl alcohol was distilled from the reaction mixture through a packed column. After 1 hr. the theoretical amount of ethyl alcohol was recovered. The residue was filtered and fractionated to give 51.8 g. (74%) of compound IV, b.p. 64° (0.2 mm.), $n^{25}\text{D}$ 1.4598, $d^{25}{}_4$ 1.0650. The infrared spectrum is consistent with the proposed structure.

Anal. Calcd. for $C_7H_8O_3$: C, 60.00; H, 5.75. Found: C, 60.27; H, 5.94.

Compound IV does not have to be isolated before proceeding to the pyrolysis step.

Pyrolysis of *sym*-**Divinylethylene Carbonate, 1,2-Divinylethylene Oxide, and 2,3-Dihydroöxepine.**—A slurry of *sym*-divinylethylene carbonate (140 g., 1.0 mole) and 5.0 g. of lithium chloride powder[13] was heated slowly to 200–210°, and the distillate was collected in a Dry Ice trap. The distillate was washed twice with cold water and dried over magnesium sulfate to give 49.7 g. of crude product. Distillation through a 20-in., helices-packed column gave a constant boiling fraction, b.p. 108° (760 mm.), with a refractive index ranging from $n^{25}\text{D}$ 1.4541 to 1.4561. A 10.7 g. sample of the distilled product was separated into two fractions by vapor phase chromatography using a 6-ft. column with 3-methyl-3-nitro-1,5-dicyanopentane on firebrick as the stationary phase. The first fraction (retention time, 12 min., column temp., 90°; flow rate, 500 ml./min.) (3.3 g.) was 4,5-dihydroöxepine (I); and the second fraction (retention time, 18 min., (6.1 g.) was 1,2-divinylethylene oxide (II).

4,5-Dihydroöxepine.—B.p. 108° (760 mm.), $n^{25}\text{D}$ 1.4632. The infrared spectrum was consistent with the proposed structure: 3055 cm.$^{-1}$ (CH stretching of *cis*-CH═CH—), 2940 and 2860 cm.$^{-1}$ (CH stretching of CH_2), 1650 cm.$^{-1}$ (nonconjugated C═C), 1448 cm.$^{-1}$ (CH_2 deformation frequency of —CH═C—CH_2), 1238 cm.$^{-1}$ (*cis*-C═C adjacent to oxygen). The near-infrared spectrum showed that terminal epoxide or terminal methylene groups were absent and the ultraviolet spectrum indicated the absence of conjugated unsaturation. The proton resonance indicated three different protons in the expected ratio of 2:1:1; peaks occurring at 7.3 τ, assigned to the hydrogens at the 4 and 5 position; 5.3 τ, hydrogens at the 3 and 6 positions; 3.42 τ, hydrogens at 2 and 7 positions (split).[14]

Anal. Calcd. for C_6H_8O: C, 74.97; H, 8.38; O, 16.65; mol. wt., 96. Found: C, 74.89; H, 8.26; O, 17.12 (Unterzaucher method); mol. wt. (f.p. benzene), 100.

Hydrogenation of 4,5-dihydroöxepine over platinum oxide resulted in a 101% uptake of 2 moles of hydrogen. The 4,5-dihydroöxepine was hydrolyzed by warming with aqueous acetic acid for 10 min. to give a solution which reduced ammoniacal silver nitrate (suggesting a rearrangement to an aldehyde). Freshly prepared 2,4-dinitrophenylhydrazine reagent was added to the hydrolyzed 4,5-dihydroöxepine. The crude derivative was purified by chromatographing it on neutral alumina and eluting with chloroform. The pure derivative was brilliant red, m.p. 215–216° (lit.,[15] m.p. for 2,4-DNP of 1-cyclopentene carboxaldehyde, 215–216°).

Anal. Calcd. for $C_{12}H_{12}N_4O_4$: N, 20.28. Found: N, 20.18.

sym-**Divinylethylene Oxide.**—B.p. 108° (760 mm.), m.p. 35°, $n^{25}\text{D}$ 1.4474. The infrared spectrum was consistent with the proposed structure: 3125 cm.$^{-1}$ (C—H), 3030 cm.$^{-1}$ (saturated C—H with low frequency due to strained ring configuration), 1887 cm.$^{-1}$ (C═C overtone), and bands at 993, 927, and 869 cm.$^{-1}$ (epoxide). The compound gave a positive periodic acid test indicating the presence of an epoxide group. The nuclear magnetic resonance spectrum indicated two different protons in the ratio 3:1; 4.97 τ, vinyl protons overlapped and 6.58 τ, protons on epoxide ring.

Anal. Calcd. for C_6H_8O: C, 74.97; H, 8.39; O, 16.67; mol. wt., 96. Found: C, 74.99; H, 8.38; O, 17.32 (Unterzaucher method); mol. wt., 95.

Acknowledgment.—The author expresses his appreciation to Dr. Anthony J. Papa, John W. Robson, and Charles B. Matthews for helpful discussions and to Dr. Heinz F. Reinhardt who first prepared compound II.

---

[13] Lithium chloride is a much more effective catalyst for the pyrolysis than other salts used previously for the pyrolysis of carbonate; U. S. Patent 2,856,413.

[14] The n.m.r. spectrum rules out the possible alternative structure, 2,3-dihydroöxepine.[2]

[15] I. Heibron, *J. Chem. Soc.*, 1827 (1949).

A General Synthesis of 3-Indolealkanoic Acids

HENRY EDWARD FRITZ

Research and Development Department, Union Carbide Olefins Company, Division of Union Carbide Corporation, South Charleston, West Virginia

Received October 18, 1962

3-Indolealkanoic acids are very active plant growth substances. 3-Indoleacetic and 3-indolebutyric acids are used commercially by nursuries to promote growth of plant cuttings, and many other interesting biological properties have been reported for these acids and their derivatives. 3-Indolecaproic acid and its amide also have excellent biological properties.[1,2] A simple one-step synthesis for the preparation of 3-indolealkanoic acids is described which involves the direct base-catalyzed reaction of lactones with indole or its derivatives.

3-Indolealkanoic acids have been prepared previously by the reaction of lactones with indole, but these syntheses generally involved several steps, or gave low yields. The reaction of butyrolactone with the potassium salt of indole at 200° has given 1-indolebutyric acid,[3] while with the magnesium iodide salt of indole at 120–130° has given 3-indolebutyric acid.[4] These syntheses required the prior preparation of the respective salts *via* involved procedures. The noncatalytic reaction of propiolactone with indole at 120° is reported to give 3-indolepropionic acid in 40–50% yield.[5] An attempt was made to duplicate this result, but only starting material was recovered in 90% yield. A reaction did occur when the temperature was raised to 245°, but the product was a nitrogen-containing polymeric acid which was not investigated further.

The reaction of lactones with indole, in the presence of base, takes place at 200–300° to give high yields of 3-indolealkanoic acids (Table I). The acids described in Table I were prepared at 250° using a reaction mixture comprising 1.0 mole of indole, 1.05 moles of lactone and 1.1 moles of base. The base used was potassium hydroxide, but sodium hydroxide or sodium methoxide also gave satisfactory results. Some skatole was produced when sodium methoxide was used.[6] No solvent was used in these preparations, but solvents, such as tetralin, methylnaphthalene, or diethylbenzene, can be used. When the reactions were run in the presence of a solvent the yields were generally lower. The purity of the crude acids, which were isolated by the

---

[1] C. H. Fawcett, R. L. Wain, and F. Wightman, *Nature*, **181**, 1387 (1958).

[2] D. G. Crosby, J. B. Boyd, and H. E. Johnson, *J. Org. Chem.*, **25**, 1826 (1960).

[3] W. Reppe, *et al.*, *Ann.*, **596**, 1 (1955).

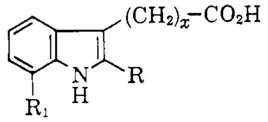
[4] F. N. Stepanov, U. S. S. R., Patent 66,681; *Chem. Abstr.*, **41**, 2087b (1947).

[5] J. Harley-Mason, *Chem. Ind.* (London), 886 (1951).

[6] E. F. Pratt and L. W. Botimer, *J. Am. Chem. Soc.*, **79**, 5248 (1957).

TABLE I

3-INDOLEALKANOIC ACIDS



R	R_1	x	Yield, %	Yield, based on unrecovered indole, %	M.p., °C. Found	M.p., °C. Lit.
H	H	2	69	94	134–135	133–134[a]
H	H	3	82	96	124	124[b]
H	H	4	43	70	105–107	105[c]
H	H	5	75	95	143–144	...
C_6H_5	CH_3	5	41	61	97.5–99.5	...

[a] R. Majima and M. Kotake, *Ber.*, **58B**, 2037 (1925). [b] See ref. 7. [c] R. H. F. Manske and L. C. Leitch, *Can. J. Res.*, **14B**, 1 (1936).

addition of water to the reaction mixture followed by acidification of the aqueous phase, was 85–98%, depending upon the reaction conditions and the reactants used. The acids with less than five carbons in the acid chain were not only obtained in lower purity but were much more susceptible to oxidation, and, therefore, more difficult to purify.

A series of five reactions was run using indole, butyrolactone, and potassium hydroxide to determine the optimum conditions for the preparation of 3-indolebutyric acid (Table II). The highest yields were obtained from the reactions run between 220 and 290° for twenty hours with an equimolar quantity of potassium hydroxide.

TABLE II

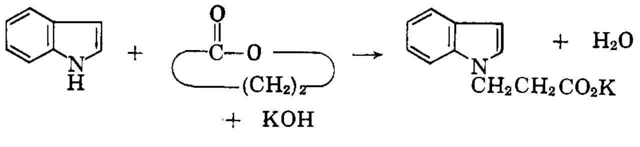
SYNTHESIS OF 3-INDOLEBUTYRIC ACID

Indole (117 g., 1.0 mole), butyrolactone (90 g., 1.05 moles), potassium hydroxide (72 g. of 85% purity, 1.09 moles)

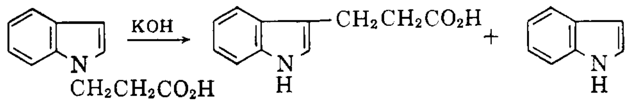
Run number	Reaction temp., °C.	Reaction time, hr.	3-Indolebutyric acid, crude Yield, %	3-Indolebutyric acid, crude Yield, based on unrecovered indole, %
1	190–200	22	16	81
2	220–250	20	67	88
3	250–290	20	82	96
4[a]	257–280	30	11	20
5	275–280	1	44	88

[a] Seven grams of potassium hydrogen instead of 72 g.

Both 1- and 3-indolepropionic acids were prepared in high yield from indole, propiolactone, and potassium hydroxide by varying the reaction temperature. 3-Indolepropionic acid was obtained in 69% yield when prepared in the usual manner at 250°. However, when the reactants were slowly heated in a stainless steel flask to 60°, a sudden exothermic reaction took place and the temperature rose to 180° with the formation of potassium 1-indolepropionate.



Since the 3-indolepropionic acid is obtained at higher temperatures, a rearrangement must take place. 1-Indolepropionic acid was rearranged to 3-indolepropionic acid by heating with an excess of potassium hydroxide at 210° for nine hours. A 41% yield of 3-indolepropionic acid was obtained along with a 36% yield of indole.



Several unsuccessful attempts were made to isolate 1-indolebutyric acid from low temperature runs using butyrolactone, indole, and potassium hydroxide, but the only acid products were 3-indolebutyric acid and nonindole containing acids.

Experimental

Procedure A. Preparation of 3-Indolealkanoic Acids Demonstrated by the Following Example for 3-Indolecaproic Acid.—There was charged to a 1-l. stainless steel rocker autoclave 117 g. (1.0 mole) of indole, 130 g. (1.14 moles) of ϵ-caprolactone, and 90 g. (1.36 moles) of potassium hydroxide pellets (85% purity). The mixture was heated to 250° in 1 hr. and then kept at 250° ± 5° for 19 hr. The brown solid from the autoclave was treated with 1 l. of water which dissolved most of the solid. This aqueous mixture was extracted with 250 ml. of isopropyl ether which upon evaporation of the isopropyl ether gave 3.0 g. of indole. The aqueous layer was acidified with concd. hydrochloric acid, whereupon the 3-indolecaproic acid separated as a tan solid. The washed and dried solid weighed 198 g., m.p. 136–141°. Recrystallization from acetic acid, benzene, methanol, or hexane improved the melting point to 143–144°. The structure of the 3-indolecaproic acid was confirmed by infrared and ultraviolet spectra, elemental analysis, and titration of the acidic function.

Anal. Calcd. for $C_{14}H_{17}O_2N$: C, 72.81; H, 7.41; N, 6.06; neut. equiv., 231.29. Found: C, 72.99; H, 7.49; N, 6.29; neut. equiv., 228.

Procedure B. Use of Solvent in the Preparation of 3-Indolebutyric Acid.—There was charged to a three-necked, 1-l. stainless steel flask equipped with a stirrer, thermowell, and a reflux condenser, which had a trapf or collecting the water of formation, 117 g. (1.0 mole) of indole, 100 g. (1.15 moles) of butyrolactone, 100 g. (1.5 moles) of potassium hydroxide pellets, and 250 g. of tetralin. The stirred mixture was heated at reflux for 10 hr. during which time a total of 36 ml. of water was collected. The mixture was treated with approximately 1 l. of water and the layers were separated. The upper organic layer weighed 269 g. and contained 11% by weight of unchanged indole. The aqueous layer was acidified with concentrated hydrochloric acid, whereupon the 3-indolebutyric acid separated as an oil which slowly crystallized. The crude product weighed 147 g., m.p. 105–118°. Recrystallizations from benzene gave crystals melting at 123–124° (lit.,[7] m.p. 124°).

The methyl ester was prepared in 75% yield, m.p. 73–74° (reported[7] m.p. 73–74°).

1-Indolepropionic Acid.—A mixture of 234 g. (2.0 moles) of indole, 160 g. (2.22 moles) of propiolactone, and 168 g. (2.43 moles) of potassium hydroxide pellets was heated with stirring in a nitrogen atmosphere. At 60°, a sudden exothermic reaction took place and the temperature rose to 180° within 1 min. and part of the reaction mixture was lost. Most of the mixture dissolved in 500 ml. of water. Extraction with isopropyl ether give 20 g. of unchanged indole. Acidification of the chilled aqueous layer with concentrated hydrochloric acid gave 269 g. (71% yield) of 1-indolepropionic acid, m.p. 80–85°, recrystallized from hexane, m.p. 89–90° (reported[8] m.p. 91°).

Anal. Calcd. for $C_{11}H_{11}O_2N$: C, 69.82; H, 5.86; N, 7.40. Found: C, 70.15; H, 6.03; N, 7.70.

Rearrangement of 1- to 3-Indolepropionic Acid.—A stirred mixture of 9 g. (0.048 mole) of 1-indolepropionic acid and 5 g. (0.076 mole) of potassium hydroxide pellets in a stainless steel flask was heated at 210° for 9 hr. The cooled mixture was diluted with 100 ml. of water and extracted with isopropyl ether. Evaporation of ether gave 2 g. of indole. After acidification of the aqueous layer, 3.7 g. of 3-indolepropionic acid was recovered.

---

(7) R. W. Jackson and R. H. F. Manske, *J. Am. Chem. Soc.*, **52**, 5029–5035 (1930).

(8) French Patent 48,570, (April 5, 1938); *Chem. Abstr.*, **33**, 176 (1939).

Another rearrangement of 1-indolepropionic acid was made at 245° for 2 hr. in a stainless steel rocker autoclave. Again, a 41% yield of 3-indolepropionic acid was obtained.

Acknowledgment.—The author thanks Mr. A. H. DuVall and Mr. S. Gottlieb for analyses and Mr. M. A. Eccles and Mr. K. E. Atkins for laboratory assistance.

Photodehydrogenation of Resin Acids

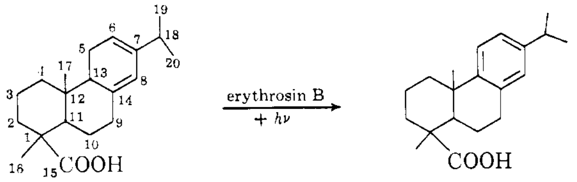
WALTER H. SCHULLER AND RAY V. LAWRENCE

Naval Stores Laboratory, Olustee,[1] *Florida*

Received November 21, 1962

The photosensitized oxidation of the seven major resin acids in pine gum has been studied in these laboratories.[2-4] It was noted that in the *absence* of oxygen, irradiation of levopimaric,[2] palustric,[3] and neoabietic[4] acids, in solution with a sensitizing dye, resulted in bleaching of the dye. It was the purpose of the present work to investigate the nature and effect of the "bleaching reaction" upon the pine gum resin acids. Ergosterol under these conditions has been shown to undergo a dehydrogenation–dimerization[5] while pentaphenylcyclohexa-1,3-diene was converted to pentaphenylbenzene.[6] The photosensitized oxidation of ergosterol and lumisterol is accompanied by dehydrogenation to heteroannular trienes.[7]

Visible light irradiation of deaerated ethanol solutions of levopimaric acid (I) and erythrosin B in varying ratios indicated that about one mole of dye was required for reaction with two moles of resin acid. Under these conditions, the product of the photochemical reaction was found to be dehydroabietic acid (II; 20% isolable yield), indicating that dehydrogenation to an aromatic system had occurred.



I II

Irradiation of palustric acid ($\Delta^{7,13}$) in the presence of a molar amount of erythrosin B also gave dehydroabietic acid (21% isolable yield) as the irradiation product.

When applied to neoabietic acid ($\Delta^{7(18),8(14)}$), the reaction under investigation gave a mixture of four volatile compounds as determined by gas chromatography of the methyl ester of the crude product, plus considerable nonvolatile material, presumably polymer. None of the volatile esters could be crystallized; however, two of the compounds exhibited ultraviolet spectra characteristic of conjugated trienes.[8]

Dehydroabietic (II), pimaric, isopimaric, and abietic ($\Delta^{7,9(14)}$) acids did not react under similar conditions. The first three have been found to be unreactive toward photosensitized oxidation as well.[4] Abietic acid has been observed to react slowly on photosensitized oxidation to give chiefly nonperoxidic products.[4,9]

An attempt was made to replace the greater part of the sensitizer with an easily reducible compound, which in itself was not a sensitizer, in order to establish a hydrogen exchange situation promoted by only a catalytic amount of light-activated sensitizer. This effort was successful with the demonstration that the irradiation of levopimaric acid in the presence of a catalytic amount of erythrosin B and a molar amount of nitromethane gave dehydroabietic acid in 17% isolable yield.

Suitable blanks were run for all the reactions herein reported which established that no reaction occurred in the dark, in the absence of sensitizing dye, in the absence of resin acid, or in the absence of nitromethane (other than a very rapid bleaching of the small amount of dye present in the latter case).

Schenck[10] has proposed that the irradiation of sensitizers results in their elevation to diradicals. He has suggested hydrogen abstraction from the substrate by the diradical to give a monoradical, as the possible course of any competing dehydrogenation reaction which might occur during photosensitized oxidation. Diradicals of the type pictured by Schuller,[3,4] *et al.*, would be especially suited geometrically for hydrogen abstraction from two adjacent carbon atoms upon a single collision, yielding a new double bond.

Experimental[11]

Varying Ratios of Levopimaric Acid to Erythrosin B.—Four 95% ethanol solutions, each 0.02 *M* in levopimaric acid, and containing $^1/_2$, $^1/_4$, $^1/_6$, and $^1/_8$ molar ratios of erythrosin B/resin acid, respectively, were charged to 100-ml. reactors,[2] purged with prepurified nitrogen, stoppered, and irradiated simultaneously, with a 15-w. fluorescent lamp. All the runs but the $^1/_2$ ratio bleached within 22 hr. while this ratio was unbleached after 111 hr. of irradiation.

A run of the $^1/_2$ ratio was made and irradiation continued until no additional change in $[\alpha]$D occurred. More erythrosin B was added (1.5/2 molar ratio) and irradiation continued for 21 hr. with no further change in $[\alpha]$D observed.

Dehydroabietc Acid (II) from Levopimaric Acid (I).—A solution of 11.9 g. of erythrosin B in 2700 ml. of 95% ethanol was filtered and 8.17 g. of levopimaric acid dissolved in the filtrate (0.005 *M* in dye and 0.01 *M* in resin acid). The solution was charged to the 40-w. reactor,[2] purged with prepurified nitrogen, the reactor sealed (stoppered), and irradiation initiated. Two external air blasts were directed on the reactor to hold the temperature around 30°. After 20 hr. of irradiation, the specific rotation became constant at $[\alpha]^{27}$D −30°. Irradiation was continued for 10 hr. more to ensure completeness of reaction. The solvent was removed under reduced pressure and the dry residue extracted with ether. The ether was filtered, washed with water, and the ether removed. The residue (8.0 g.) exhibited no absorption maximum in the 272-mμ region. It was converted to a cyclo-

---

[1] One of the laboratories of the Southern Utilization Research and Development Division, Agricultural Research Service, U. S. Department of Agriculture. Article is not copyrighted.

[2] R. N. Moore and R. V. Lawrence, *J. Am. Chem. Soc.*, **80**, 1438 (1958).

[3] W. H. Schuller, R. N. Moore, and R. V. Lawrence, *ibid.*, **83**, 1734 (1960).

[4] W. H. Schuller and R. V. Lawrence, *ibid.* **83**, 2563 (1961).

[5] L. F. Fieser and M. Fieser, "Steroids," Reinhold Publishing Corp., New York, N. Y., 1959, pp. 104–108.

[6] G. R. Evanega, W. Bergmann, and J. English, Jr., *J. Am. Chem. Soc.*, **27**, 13 (1962).

[7] A. Windaus and J. Brunken, *Ann.*, **460**, 225 (1928); P. Bladon, *J. Chem. Soc.*, 2176 (1955).

[8] K. Alder and H. von Brachel, *Ann.*, **608**, 195 (1957); H. H. Inhoffen, K. Bruckner, R. Grundel, and G. Quinkert, *Ber.*, **87**, 1407 (1954); H. H. Inhoffen and G. Quinkert, *ibid.*, **87**, 1418 (1954).

[9] W. H. Schuller and R. V. Lawrence, *FLACS*, **15**, No. 8, 23 (1962); Florida Section, Meeting-in-Miniature, American Chemical Society, May 11, 1962, Jacksonville, Fla.

[10] G. O. Schenck, *Naturwissenschaften*, **40**, 205 (1953).

[11] All melting points are uncorrected and all specific rotations and ultraviolet spectra are in 95% ethanol.