containing 0.32 g. (0.002 mole) of anhydrous *p*-toluenesulfonic acid, and the solution was refluxed gently for four hours. Three water washings removed the *p*-toluenesulfonic acid. The solution was dried over sodium sulfate and the toluene separated under reduced pressure. A flash distillation in a high vacuum removed the distillable components and these materials were fractionated through a 20″ × $^1/_4$″ rotating platinum-band column. Three and eight-tenths grams (0.016 mole) (45%) of 3-methyl-5-benzyloxy-6-chloro-1,3-hexadiene, b.p. 86–89° (0.2 mm.), n^{20}_D 1.5301, was isolated. This product was characterized by its infrared absorption spectrum and by elemental analysis.

Anal. Calcd. for $C_{14}H_{17}OCl$: C, 71.04; H, 7.19; Cl, 15.01. Found: C, 71.00, 70.96; H, 7.07, 7.20; Cl, 13.85, 13.60.

Use of Infrared Absorption Spectra to Follow the Dealcoholation Reaction.—The required amount of *p*-toluenesulfonic acid monohydrate was dissolved in toluene. The solution was dehydrated by vigorous refluxing for 15 minutes under a condenser equipped with a water trap. The anhydrous solution was cooled to 40–50°, and the compound to be dealcoholated was added in a single portion. The first 1.0-ml. aliquot was removed immediately. The reaction mixture was brought to reflux temperature, and 1-ml. aliquots were then removed at regular intervals. The infrared absorption scans were obtained for each aliquot immediately after removal from the reaction mixture. Graphs showing changes in intensity of various characteristic absorptions were then prepared.

In Fig. 1, the dealcoholation of 1-methoxy-3-methyl-5-ethoxy-6-chloro-2-hexene is described. In this run, a 20:1 molar ratio of adduct to *p*-toluenesulfonic acid was used; the concentration of adduct in the toluene was 17% by weight. In the plotting of the absorption data obtained, the variance in reactant concentration and cell thickness was corrected to a concentration of 20 g. adduct/100 ml. of toluene with an absorption path of 1 mm. In the graph, curve A is a plot of infrared absorptions at 3.6 μ and represents a decrease in concentration of the starting material. Curve B is a plot of infrared absorptions at 11.1 μ and shows changes in concentration of the 1,3-diene formed in the reaction. Changes in intensity of infrared absorptions at 5.9 μ are described by plot C; this plot represents the appearance of an uncharacterized product, presumed to be formed largely at the expense of the 1,3-diene.

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[CONTRIBUTION FROM THE MCPHERSON CHEMICAL LABORATORY, OHIO STATE UNIVERSITY]

Synthesis of a Series of Substituted Phenylpropiolic Acids

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The synthesis of phenylpropiolic and of *o*-, *m*- and *p*-chloro-, methoxy- and nitrophenylpropiolic acids is described. A new procedure for alkaline dehydrohalogenation is illustrated in several of the syntheses.

The reasons for the synthesis of a series of *ortho*-, *meta*- and *para*-substituted phenylpropiolic acids are given in the accompanying paper.[2] In this paper are described the synthesis of phenylpropiolic acid and the *o*-, *m*- and *p*-chloro, nitro and methoxy analogs.

In the synthetic work prime attention was paid to purity of product so that the yields reported do not reflect efforts to reach a maximum. All of the acids were prepared by dehydrobromination of the corresponding dibromocinnamic acid or ester. In each case by-products were obtained which rendered the isolation of pure propiolic-type acid difficult. Since each case was different no attempt at generalization concerning conditions for reaction or purification will be made. Rather each experimental procedure will be described.

A new procedure was used for some of the alkaline dehydrobrominations. This procedure involves addition of a small excess of sodium hydride to a benzene solution of the dibromocinnamate followed by small additions of absolute alcohol. The alcohol reacts with sodium hydride to form sodium ethoxide and hydrogen (equation 1). The sodium ethoxide then removes hydrogen bromide from the dibromoester thereby regenerating alcohol (equation 2).

$$C_2H_5OH + NaH \longrightarrow C_2H_5ONa + H_2 \qquad (1)$$

$$C_2H_5ONa + (HBr) \longrightarrow C_2H_5OH + NaBr \qquad (2)$$

The fact that sodium ethoxide is the real dehydrobrominating agent is shown by the failure of the benzene solution of dibromoester to react with sodium hydride, even at reflux. Indeed it is important that the benzene–dibromide solution be inert to sodium hydride else a violent reaction might occur on adding the relatively large amount of sodium hydride needed.

In principle a small amount of alcohol could suffice to complete a large scale reaction. In practice occasional small additions of alcohol are needed. In any event this method drastically reduces the amount of alcohol present and, in certain cases at least, markedly improves the yield. For example, with sodium ethoxide in ethanol ethyl dibromocinnamate was converted mainly into ethyl β-ethoxycinnamate[3] whereas by our procedure a good yield of pure phenylpropiolic was obtained. However, our procedure could not be used for any of the nitrocinnamic ester dibromides.

The sodium hydride procedure could be generalized by using alcohols other than ethyl or any compound which will react with sodium hydride to form a conjugate base capable of effecting dehydrohalogenation. Since the solvent is mainly benzene the tendency for solvolytic side reactions with certain types of halogen compounds should be minimized.

Experimental[4]

Phenylpropiolic Acid.—A solution of 115 g. (0.65 mole) of ethyl cinnamate in 250 ml. of methylene chloride was

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(1) Holder of a National Science Foundation Fellowship, 1952–1953.

(2) M. S. Newman and S. H. Merrill, THIS JOURNAL, **77**, 5552 (1955).

(3) V. L. Leighton, *Am. Chem. J.*, **20**, 136 (1898). The procedure in "Organic Syntheses," Coll. Vol. II, John Wiley and Sons, Inc., New York, N. Y., p. 515, uses potassium hydroxide in 95% alcohol and is preferable to that of Leighton.

(4) All melting points are corrected and were determined with calibrated Anschütz total immersion thermometers.

treated with a 105 g. of bromine at 15°. Eight hours were required for completion of the reaction. After evaporation of the solvent the crude dibromo ester was dissolved in 300 ml. of dry benzene in a 2-l. flask equipped with a stirrer and a reflux condenser protected with a drying tube. To the solution was quickly added 32.0 g. (1.33 moles) of sodium hydride and the suspension was heated to boiling. Heating was discontinued and 2 ml. of abs. ethanol was added while stirring. After a short time the evolution of hydrogen became vigorous. By adjusting the rate of heating or cooling the reaction rate was kept as large as the capacity of the condenser would allow. Additional 2-cc. portions of ethanol were put in to maintain the reaction which lasted three hours. To decompose any remaining hydride 20 cc. of ethanol was finally added, and the flask was cooled in ice. About 200 cc. of ethyl ether was added followed by sufficient 5% hydrochloric acid to acidify. Water was added to dissolve the sodium bromide, and the two layers were separated. The organic layer was washed free of acids with potassium carbonate solution, then dried and fractionated through an 18-inch packed column at 1 mm. The fraction, 65 g., b.p. 96–108°, $n^{25}\text{D}$ 1.5541, was crude ethyl phenylpropiolate. The fraction, 39 g., b.p. 108–120°, $n^{25}\text{D}$ 1.5385, was principally ethyl β-ethoxycinnamate.[3] A small quantity (6.8%) of pure phenylpropiolic acid was obtained after recrystallization of the acid present in the carbonate extract.

In a typical saponification 8.0 g. of crude ethyl phenylpropiolate was added to a solution of 2.2 g. of sodium hydroxide and 3 cc. of ethanol in 25 cc. of water. The mixture was warmed and shaken until homogeneous, then allowed to stand a few hours. The crude acid thus produced was recrystallized thrice from carbon tetrachloride to yield 4.8 g. (51% based on ethyl cinnamate) of pure phenylpropiolic acid,[5] m.p. 136.9–137.5°. The above procedure is markedly superior to that using alcoholic sodium ethoxide for the latter produced considerably more ethyl β-ethoxycinnamate.[3]

o-**Chlorophenylpropiolic Acid.**—The addition of 305 g. of bromine to a solution of 400 g. of ethyl *o*-chlorocinnamate in 500 cc. of methylene chloride occurred so rapidly after an induction period that cooling was necessary to prevent refluxing. Soon after all of the bromine had been added the excess bromine and solvent were removed under reduced pressure. Benzene was added and the solution distilled for a few minutes to remove any moisture. An aliquot of this solution (163 g. of crude ester in 200 cc. of benzene) was treated with 22 g. of sodium hydride and then with continuous stirring 3 cc. of ethanol. Soon the reaction refluxed so vigorously that some cooling was needed for an hour. The mixture was then heated at reflux for one hour at which time no more hydrogen was being evolved. The reaction mixture was poured into water and separated into acidic and neutral fractions. From the acid fraction 6.4 g. (8%) of good *o*-chlorophenylpropiolic acid, was obtained. Distillation of the neutral fraction afforded 82.2 g. (89.5%) of crude ethyl *o*-chlorophenylpropiolate, b.p. 110–117° at 1–2 mm., $n^{29}\text{D}$ 1.5590–1.5580. The crude ester was saponified with a small excess of 20% sodium hydroxide containing a little alcohol. The alkaline solution was extracted once with ether (discarded extract) and slowly acidified with hydrochloric acid. A definite break in the precipitation of solid acid occurred when about 5% of acid had been added.[6] After removal of this acid (*o*-chlorocinnamic acid) the remaining acid was precipitated, collected and dried. It was purified as the potassium salt by taking up in hot 3% alcoholic potassium hydroxide and cooling. The free acid was recrystallized from benzene to a m.p. of 132.7–133.8°[7] and was obtained in about 54% yield (over-all from ethyl *o*-chlorocinnamate).

p-**Chlorophenylpropiolic Acid.**—The preparation and purification of this acid was similar to that for the *o*-isomer. However, the crude ester mixture from the dehydrobromination could not be fractionated because of polymerization of some component. During attempted rectification a large amount of a yellow crystalline product was formed. Accordingly heating was discontinued and the liquid ester extracted with petroleum ether. The solid remaining melted sharply near 246° when recrystallized from dimethylformamide and alcohol but was not further examined. On saponification of the liquid esters and purification by partial acidification of the alkaline solution as above followed by purification through the potassium salt, pure *p*-chlorophenylpropiolic acid,[8] m.p. 192–193° dec. after sintering at 185°, was obtained as colorless plates from benzene.

Anal. Calcd. for $C_9H_5O_2Cl$: C, 19.6; neut. equiv., 180.6. Found: C, 19.5; neut. equiv., 180.4 (av.).

m-**Chlorophenylpropiolic Acid.**—*m*-Chlorobenzaldehyde[9] was condensed with malonic acid, and the ethyl ester of the resulting *m*-chlorocinnamic acid was brominated in the usual way. Dehydrobromination was accomplished by refluxing the dibromoester for three hours in an excess of ethanolic potassium hydroxide. The hot solution was decanted from the potassium bromide and on cooling the potassium salt of *m*-chlorophenylpropiolic acid crystallized. After recrystallization from ethanol this salt was dissolved in water and acidified. The resulting acid was taken up in an ether–benzene mixture, dried and concentrated. By adding high-boiling petroleum ether to the hot solution *m*-chlorophenylpropiolic acid,[10] m.p. 144.3–145.1°, was obtained. The over-all yield of pure acid from aldehyde was 52%.

p-**Nitrophenylpropiolic Acid.**—Ethyl *p*-nitrocinnamate[11] was brominated in methylene chloride over a period of 24 hours. To 132 g. of the dibromoester in 200 ml. of dry benzene in a flask equipped with a stirrer, dropping funnel and reflux condenser topped with a drying tube was added dropwise sodium ethoxide solution prepared by dissolving 19 g. of sodium in 300 cc. of absolute alcohol. The benzene solution was heated nearly to reflux during the addition and the rate of addition was adjusted so that an excess of base was present for no more than a few seconds. If the color began to darken the addition was interrupted. The addition required an hour and the heating was continued another hour. After cooling the solution was acidified and water was added to bring the volume up to 1.5 l. The layers were separated, the aqueous layer was extracted with two portions of ether, and the combined organic layer was separated into neutral and acidic fractions. From the acid fraction 8.5 g. of crude *p*-nitrophenylpropiolic acid was obtained. The neutral portion, b.p. 150–155° at 0.2 mm., was recrystallized twice from ethanol to yield 41 g. of pure ethyl *p*-nitrophenylpropiolate,[12] m.p. 123.0–123.8°.

Saponification of small quantities of this ester was accomplished by dissolving it in dioxane, adding a slight excess of 10% aqueous sodium hydroxide and warming slightly until homogeneous. The solution was evaporated to dryness with an air stream and the sodium salt was recrystallized from 10% aqueous sodium hydroxide, washed with alkali, dissolved in water and acidified. The *p*-nitrophenylpropiolic acid obtained after crystallization from benzene melted with decomposition at 204–205° on slow heating.[13] The yield from ethyl *p*-nitrocinnamate was 59%.

m-**Nitrophenylpropiolic Acid.**—Ethyl *m*-nitrocinnamate in methylene chloride required 24 hours to react with the equivalent amount of bromine. The resulting dibromoester could not be dehydrobrominated successfully in one operation because *m*-nitro-allo-α-bromocinnamic acid (carboxyl and nitrophenyl groups *cis*) was formed as the principal intermediate and resisted further elimination until it had been isomerized to the *trans* configuration.[14] To 19 g. of sodium hydroxide dissolved in a mixture of 170 cc. of water and 25 cc. of dioxane was added 28.7 g. of the dibromoester. The mixture was stirred for two hours at 50°. The resultant solution was diluted with an equal volume of water, acidified and extracted with two portions of chloroform. The chloroform solution was dried and evaporated to about 75 cc. Bromine was added and an excess was

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(5) C. Glaser, *Ann.*, **154**, 140 (1870), reported m.p. 136–137°.

(6) M. S. Newman, R. B. Taylor, T. Hodgson and A. B. Garrett, THIS JOURNAL, **69**, 1784 (1947).

(7) E. Bergmann and A. Bondi, *Ber*, **66**, 278 (1933); M. M. Otto, THIS JOURNAL, **56**, 1393 (1934), reported a m.p. of 131–132°.

(8) C. J. Wilson and H. H. Wenzke, THIS JOURNAL, **57**, 1265 (1935), reported a m.p. of 147° but gave no analysis or neutral equivalent.

(9) W. H. Carothers, *Org. Syntheses*, **13**, 28 (1933).

(10) M. M. Otto, THIS JOURNAL, **56**, 1393 (1934), reported m.p. 140–141°.

(11) C. L. Muller. *Ann.*, **212**, 122 (1882).

(12) V. B. Dreusen, *Ann.*, **212**, 156 (1882), reported m.p. 126°.

(13) F. C. Badder and L. S. El-Assal, *J. Chem. Soc.*, 1267 (1948), reported m.p. 201–202° dec.; V. B. Dreusen,[12] reported m.p. 198° dec.

(14) S. Reich and S. Koehler, *Ber.*, **46**, 3727 (1913), studied the isomeric *m*-nitrophenyl-α-bromocinnamic acids thoroughly.

maintained for a period of three days. The *m*-nitro-α-bromocinnamic acid (*trans*, m.p. 217°) which crystallized during this period was collected and dissolved in 30 ml. of 15% aqueous sodium hydroxide. Sodium *m*-nitrophenylpropiolate crystallized from this solution on standing. This salt was twice recrystallized from 10% sodium hydroxide. The free *m*-nitrophenylpropiolic acid after crystallization from benzene–ligroin melted at 143.7-144.4°.[14] The yield was 5.5 g. (38%).

o-**Nitrophenylpropiolic Acid.**—Crude *o*-nitrocinnamic acid was obtained by acid hydrolysis of the residue from the separation[11] of ethyl *p*-nitrocinnamate from the mixed nitro esters. Since *o*-nitrocinnamic acid precipitates first when mineral acid is added to a sodium carbonate solution of the crude acid, fractional precipitation[6] followed by recrystallization from ethanol afforded pure acid, m.p. 240–243° w. decomp. The ethyl ester required six days to brominate in methylene chloride at room temperature. The dibromoester was dissolved in dry benzene and a 5% sodium ethoxide solution containing three equivalents was added dropwise at room temperature with stirring. After two-thirds of the alkoxide was added discoloration began. Slightly more than one equivalent of water was added to saponify the ester and the remainder of the alkoxide was added. The solution was acidified, a large quantity of water was added, and the organic material was taken into ether. The organic acid was extracted with potassium carbonate solution. The free *o*-nitrophenylpropiolic acid after recrystallization from hot (90°) water (carbon) melted at 160.5-161.0° dec.[15]

p-**Methoxyphenylpropiolic Acid.**—*p*-Methoxy-α-bromocinnamic acid (*trans*, m.p. 188–189°) was dehydrobrominated by refluxing it in excess ethanolic potassium hydroxide for 7 hours. The potassium salt crystallized on cooling and was recrystallized from ethanol. After two recrystallizations from benzene the free *p*-methoxyphenylpropiolic acid, m.p. 144.0–144.4°,[16] was obtained in a yield of 83%.

m-**Methoxyphenylpropiolic Acid.**—*m*-Methoxycinnamic acid was brominated in boiling carbon tetrachloride while irradiating it with a quartz mercury discharge tube immersed in the solution.[17] On cooling the dibromoacid separated and was converted to the corresponding monobromocinnamic acid by standing two days in an ethanolic potassium hydroxide solution at room temperature. After acidification the alcohol was evaporated with a stream of air and the organic acid was taken up in chloroform. This solution was irradiated 24 hours by the immersed mercury discharge tube. The resulting *trans*-monobromoacid was purified by precipitating as the barium salt. The monobromoacid was refluxed for four hours in alcoholic potassium hydroxide which in the usual manner yielded *m*-methoxyphenylpropiolic acid, m.p. 107.8–108.8°,[18] in 55% yield after recrystallization from chloroform–petroleum ether.

o-**Methoxyphenylpropiolic Acid.**—Ethyl *o*-methoxycinnamate was brominated at −10° in methylene chloride. Dehydrobromination by the sodium hydride method previously described yielded an oil which was fractionated through an 18-in. packed column at 0.5 mm. Infrared spectrograms showed that the fraction boiling at 128–130° ($n^{20}\mathrm{D}$ 1.562) contained some acetylenic ester. Isolation was accomplished by taking advantage of the rapid saponification of the phenylpropiolic ester, using a quantity of ethanolic potassium hydroxide estimated as equivalent to one third of the ester mixture present. After evaporation of the alcohol the residue was taken up in water and extracted with ether. The aqueous portion was partially acidified to precipitate a small amount of *o*-methoxycinnamic acid, m.p. 185–186°. Further acidification afforded a 9% yield of *o*-methoxyphenylpropiolic acid, m.p. 128.0–128.4° dec.,[19] after three recrystallizations from benzene–ligroin.

The ethyl esters of all of the phenylpropiolic acids were made by direct treatment with alcohol and hydrogen chloride. Their properties and analyses are recorded in Table I. They were shown to be free of β-ethoxycinnamate type impurity by tests with 2,4-dinitrophenylhydrazine reagent.

TABLE I

PHYSICAL CONSTANTS OF ETHYL ESTERS OF SUBSTITUTED PHENYLPROPIOLIC ACIDS

Substituent	Constants	Analyses, % Calcd.	Found
H	$n^{25}\mathrm{D}$ 1.5490	C, 75.88	75.86
		H, 5.79	5.75
o-Cl	$n^{25}\mathrm{D}$ 1.5604	Cl, 17.00	17.20
m-Cl	$n^{25}\mathrm{D}$ 1.5586	Cl, 17.00	17.07
o-NO_2	M.p. 57.3–58.1[a]		
m-NO_2	M.p. 58.0–58.6	C, 60.26	60.36
		H, 4.14	3.94
p-NO_2	M.p. 123.0–123.8[b]		
o-CH_3	$n^{25}\mathrm{D}$ 1.5592	C, 70.61	69.99
		H, 5.93	5.72
m-OCH_3	$n^{25}\mathrm{D}$ 1.5547	C, 70.61	70.53
		H, 5.93	6.09
p-OCH_3	$n^{22}\mathrm{D}$ 1.5675	C, 70.61	70.87
		H, 5.93	6.11

[a] A. Baeyer, *Ber.*, **13**, 2259 (1880), reported m.p. 60–61°. [b] B. Drewsen, *Ann.*, **212**, 154 (1882), reported m.p. 126°.

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(15) C. L. Muller, ref. 11, reported a m.p. of 157° dec.

(16) E. Bergmann and A. Bondi, *Ber.*, **66**, 278 (1933), reported m.p. 141–143° dec.

(17) J. I. Jones and T. C. James, *J. Chem. Soc.*, 1600 (1935).

(18) Ref. 18 reported a m.p. of 109°.

(19) M. Reimer and M. Howard, THIS JOURNAL, **50**, 196 (1928), reported a m.p. of 124–125° dec.