Acknowledgment.—We especially appreciate the kindness of Dr. D. J. Collins, Bournemouth Municipal College of Technology and Commerce, Lansdowne, Bournemouth, England, who prepared and sent us samples so that we might compare them directly with the compounds ($C_{16}H_{30}N_2S_2$ and $C_9H_{17}NS_2$) obtained in our laboratory. We are grateful to Professor Klaus Biemann, Massachusetts Institute of Technology, Cambridge, Mass., for determination of the mass spectra.

Crossed Cannizzaro Reactions

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Several pairs of aldehydes (including benzaldehyde, substituted benzaldehydes, and furfural) have been subjected to the conditions under which the Cannizzaro reaction usually occurs. Methods adequate for analyzing the resulting mixtures have been developed and tested. The observed disproportionations correspond qualitatively to what would be expected from (a) combined inductive and resonance influences contributed by *m*-nitro-, *p*-bromo-, and *p*-methoxy-substituents on benzaldehyde and (b) the previously observed furfural:benzaldehyde disproportionation ratio.

The work of Davidson and Bogert,[1] which involved the use of formaldehyde and an aromatic aldehyde in a crossed Cannizzaro reaction to give the corresponding aromatic carbinol in good yield, attracted some particular attention to this reaction and has become a frequently used preparative procedure. Soon after the publication of the work just mentioned, Bailar, Barney, and Miller[2] reported the results of a number of crossed Cannizzaro reactions involving pairs of aromatic aldehydes (benzaldehyde and substituted benzaldehydes). The reaction of a mixture of benzaldehyde and furfural with strong sodium hydroxide solution also has been investigated.[3]

This report includes results of experiments which represent extensions of the work of Bailar, Barney, and Miller and that on the benzaldehyde–furfural mixture. Substituted benzaldehydes with substituents of quite different types have been used, and furfural has been included as a component of three reaction mixtures. The pairs of aldehydes are listed in Table I. So far as possible, the crossed Cannizzaro reactions were carried out by the procedure used in the benzaldehyde–furfural study. It is to be noted, then, that the systems were *not* peroxide-free.

The purpose of the investigation was to determine the disproportionations which would occur when the components of the several aldehyde mixtures simultaneously undergo oxidation and reduction in the Cannizzaro reaction.

Analyses of the resultant alcohol and acid mixtures were necessary to determine the extents of the disproportionations. After considerable exploratory work with the various mixtures, methods were developed and tested—necessarily differing from one mixture to another—which yielded results adequate for the problems at hand. Details of the procedures are described in the Experimental, and some test data are listed also. Although complete agreement was not realized between alcohol-mixture and acid-mixture analytical data, the results are of similar magnitudes, and the averages permit an ordering of the several aldehydes representing relative individual susceptibilities to oxidation and to reduction in the Cannizzaro reaction.

From the data in Table I, it is obvious, for example, that *m*-nitrobenzaldehyde is (relatively) extensively oxidized as contrasted to *p*-anisaldehyde, which is much less extensively oxidized—*i.e.*, much more extensively reduced. On the bases of this and prior investigations,[2,3] the five aldehydes studied can be arranged (in order of diminishing susceptibility to oxidation): *m*-nitrobenzaldehyde, furfural, *p*-bromobenzaldehyde, benzaldehyde, and *p*-anisaldehyde. With reference to benzaldehyde and the substituted benzaldehydes, this order correlates with expected combined resonance and inductive influences of the substituent groups on the formyl group, as these should contribute to ease of (a) hydroxide ion attack and (b) hydranion transfer; the relative position of furfural in the series is in agreement with its relationship to benzaldehyde and indirectly, then, to its expected relationships to the substituted benzaldehydes.

Information concerning experimental details is included in the Experimental.

Experimental

Materials. Benzaldehyde.—Practical benzaldehyde was distilled fractionally under reduced pressure in an atmosphere of nitrogen, b.p. 71.5° (18 mm.) [lit.,[3] b.p. 69° (17 mm.)].

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TABLE I

CROSSED CANNIZZARO REACTIONS

Reaction No.	Aldehydes	Acids Obtained, Wt., G.	Alcohols Obtained, Wt., G.	Acids and Alcohols, Total Wt., Calcd., G.	Yield, %	Disproportionations; Mol. Ratios				
						Acid$_1$–Acid$_2$		1/Alcohol$_1$–Alcohol$_2$		Average
1	*m*-Nitrobenzaldehyde and furfural	28.2	24.5	53	99	*m*-Nitrobenzoic–furoic	1.19:1	*m*-Nitrobenzyl–furfuryl	1.28:1	
2		27.8	24.8	53	99		1.11:1		1.22:1	1.20:1
[a]	*p*-Bromobenzaldehyde and benzaldehyde									1.3:1[a]
3	Furfural and *p*-bromobenzaldehyde	7.8	6.2	15	93	Furoic–*p*-bromobenzoic	1.47:1	Furfuryl–*p*-bromobenzyl	1.22:1	
4		8.1	6.0	15	94		1.45:1		1.49:1	
5		15.0	14.8	30	99		1.22:1		1.1:1	1.33:1
[b]	Furfural and benzaldehyde									1.69:1[b]
6	*m*-Nitrobenzaldehyde and benzaldehyde	28.9	25.5	55	99	*m*-Nitrobenzoic–benzoic	1.82:1	*m*-Nitobenzyl–benzyl	1.72:1	
7		28.6	25.6	55	99		1.82:1		1.79:1	1.79:1
8	Benzaldehyde and *p*-anisaldehyde	23.6	25.4	52	94	Benzoic–*p*-anisic	1.89:1	Benzyl–anisyl	2.62:1	
9		23.9	27.8	52	99		1.7:1		2.13:1	2.09:1
[a]	*p*-Bromobenzaldehyde and *p*-anisaldehyde									2.25:1[a]
10	Furfural and *p*-anisaldehyde	18.5	30.5(22[c])	50	98(81[c])	Furoic–*p*-anisic	5.0:1	Furfuryl–anisyl	4.0:1	
11		16.3	32.8(22.1[c])	50	98(77[c])		5.55:1		4.76:1	4.83:1

[a] See ref. 2. [b] See ref. 3. [c] After distillation.

Benzyl Alcohol.—Benzyl alcohol was distilled fractionally under reduced pressure, b.p. 78° (2 mm.) [lit.,[3] b.p. 94° (10 mm.)].

Benzoic Acid.—Reagent grade benzoic acid was recrystallized from water; m.p. 122–122.5° (lit.,[3] m.p. 122.1–122.2°); total acidity (as benzoic acid) by titration, 99.9%.

***p*-Bromobenzaldehyde.**—This compound was prepared[4] in 84% yield (crude). It was dissolved in ether, and the ethereal solution was washed three times with 10% sodium carbonate and twice with water. The ether was removed by distillation, and the residue was dried over calcium chloride in a desiccator, m.p. 57–58° (lit.,[4] m.p. 55–57°).

***p*-Bromobenzyl Alcohol.**—This compound was prepared from *p*-bromobenzaldehyde by the method[5] reported for the preparation of *p*-tolylcarbinol. The crude product was recrystallized from dilute ethanol; yield, 66%; m.p. 75–76° (lit.,[6] m.p. 76–76.5°).

***p*-Bromobenzoic Acid.**—*p*-Bromobenzoic acid (Eastman) was recrystallized from dilute propanol; m.p. 252–254° (lit.,[7] m.p. 254.5°); total acidity (as *p*-bromobenzoic acid) by titration, 100.4%.

Furfural.—Technical furfural[8] was distilled fractionally under reduced pressure in an atmosphere of nitrogen, b.p. 63.5° (20 mm.) [lit.,[3] b.p. 62° (17 mm.)].

Furfuryl Alcohol.—Technical furfuryl alcohol[8] was distilled fractionally under reduced pressure in an atmosphere of nitrogen; b. p. 60° (2 mm.); n^{20}_{D} 1.4870 [lit.,[3] b.p. 70° (10 mm.); n^{20}_{D} 1.4873].

Furoic Acid.—Technical furoic acid[8] was recrystallized from water; m.p. 129.5–130.5° (lit.,[3] m.p. 130.8–131°); total acidity (as furoic acid) by titration, 99.5%.

***p*-Anisaldehyde.**—*p*-Anisaldehyde (Eastman) was distilled fractionally under reduced pressure in an atmosphere of nitrogen, b.p. 95° (1 mm.) [lit.,[9] b.p. 111–114° (4 mm.)].

Anisyl Alcohol.—Anisyl alcohol (Eastman) was distilled fractionally; b.p. 104° (1 mm.) [lit.,[10] b.p 127–130° (8 mm.)]; n^{20}_{D} 1.5448.

***p*-Anisic Acid.**—*p*-Anisic acid (Eastman), which melted at 186–187° (lit.,[11] m.p. 185°), was used; total acidity (as *p*-anisic acid) by titration, 100.1%.

***m*-Nitrobenzaldehyde.**—A sample of *m*-nitrobenzaldehyde, which melted at 57–58° (lit.,[12] m.p. 58°), was used.

***m*-Nitrobenzyl Alcohol.**—Practical *m*-nitrobenzyl alcohol was distilled fractionally under reduced pressure in an atmosphere of nitrogen, b.p. 149° (2 mm.) [lit.,[13] b.p. 168–170° (6 mm.)].

***m*-Nitrobenzoic Acid.**—*m*-Nitrobenzoic acid (Eastman) was used; m.p. 141–142° (lit.,[14] m.p. 142°); total acidity (as *m*-nitrobenzoic acid) by titration, 100.0%.

Sodium Hydroxide Solutions.—Sodium hydroxide solutions used for titrations were standardized against potassium acid phthalate.

Analytical Procedure: Acid Mixtures. *m*-Nitrobenzoic and Furoic Acids.—The Dumas nitrogen method was used to determine the percentage of *m*-nitrobenzoic acid in a sample of a mixture of these acids isolated from a reaction mixture. From the total acidity of the acid mixture and from the foregoing, the percentage of furoic acid in the sample of the mixture was calculated.

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Furoic and *p*-Bromobenzoic Acids.—The amount of *p*-bromobenzoic acid in a sample of a mixture of these acids isolated from a reaction mixture was determined by the method described previously[3] for benzoic acid in benzoic-furoic acid mixtures. From total acidity and the foregoing, the percentage of furoic acid in the sample was calculated.

Results obtained by this method with mixtures of known compositions were as follows: mixtures as prepared—53.96, 55.01, 58.61, and 66.51% *p*-bromobenzoic acid; found by analysis—53.63, 54.60, 58.48, and 65.84% *p*-bromobenzoic acid.

***m*-Nitrobenzoic and Benzoic Acids.**—The composition of a sample of a mixture of these acids isolated from a reaction mixture was determined as described above for a mixture of *m*-nitrobenzoic and furoic acids.

Benzoic and *p*-Anisic Acids.—The composition of a mixture of these acids was calculated from the total acidity of a weighed sample as determined by titration.[15] Because both acids are stable when treated with alkaline potassium permanganate solution, a mixture of the acids isolated from a reaction mixture (or a prepared mixture of known composition) was treated as follows—to remove admixed impurities—prior to weighing the sample for titration. About 5 g. of the acid mixture was dissolved in 30 ml. of 10% sodium hydroxide solution. The solution was heated to the boiling point, and 25 ml. of saturated potassium permanganate solution was added. After the mixture had been permitted to stand for 10 min., the excess permanganate was destroyed by the addition of saturated sodium bisulfite solution. The cool solution was acidified with 45 ml. of dilute sulfuric acid (1:1), and any manganese dioxide present was dissolved by the addition of more bisulfite solution. The solution was refluxed gently for 1 hr. and then transferred to an extractor,[3] and the purified acid mixture was recovered in the usual manner. The mixture was stored in a vacuum desiccator until constant weight was attained.

Mixtures of known compositions gave the following results: mixtures as prepared—29.26, 34.28, 61.96, 62.53, 64.95, and 76.03% *p*-anisic acid; found by analysis—29.99, 34.88, 62.06, 63.23, 65.30,[16] and 76.12% *p*-anisic acid.

Furoic and *p*-Anisic Acids.—A mixture of these acids was analyzed by the method described previously[3] for a furoic-benzoic acid mixture.

Data for mixtures of known compositions are as follows: mixtures as prepared—41.69, 46.12, and 48.44% *p*-anisic acid; found by analysis—40.71, 44.37, and 46.60% *p*-anisic acid.

Analytical Procedures: Alcohol Mixtures. *m*-Nitrobenzyl and Furfuryl Alcohols.—The composition of a mixture of these alcohols isolated from a reaction mixture was determined as follows: the amount of *m*-nitrobenzyl alcohol in a sample was found by a Dumas nitrogen analysis, and the amount of furfuryl alcohol in the mixture was calculated by difference.

Furfuryl and *p*-Bromobenzyl Alcohols.—The composition of a mixture of these alcohols isolated from a reaction mixture or a prepared mixture of known composition was determined in the following manner. From 0.5 to 1 g. of the alcohol mixture (warmed gently to insure homogeneity before weighing) was dissolved in 2 ml. of *p*-dioxane in a flask attached to a reflux condenser. While the mixture was agitated, 100 ml. of saturated potassium permanganate solution, to which had been added 10 ml. of 10% sodium hydroxide solution, was added in several portions through the condenser, and the condenser was washed down with a small amount of water. The reaction proceeded spontaneously and exothermically. Any permanganate color which remained in the mixture after it had been agitated for 15 min. was discharged by gentle heating. The mixture was cooled and then acidified by the addition of 15 ml. of dilute sulfuric acid (1:1). Separated manganese dioxide was dissolved by the addition of saturated sodium bisulfite solution; gentle refluxing for 1 hr. expelled sulfur dioxide. The solution was cooled and transferred (including several washings with ether) to an extractor[3] and extracted with ether for 10–12 hr. The ether solution was washed with water (3 × 25 ml.) and transferred to a distilling flask fitted with a 50-cm. Vigreux column; all but 5–10 ml. of the ether was removed by distillation. The residue was placed in a vacuum desiccator (calcium chloride) for 2 days. A weighed sample of the solid residue was dissolved in acid-free ethanol, and the amount of *p*-bromobenzoic acid was determined by titration (phenolphthalein) with standardized sodium hydroxide solution.

That the method gives results of sufficient accuracy for the problem at hand is shown by the following data obtained from mixtures of the two alcohols of known compositions: mixtures as prepared—37.25, 47.51, 51.01, 52.05, and 100% *p*-bromobenzyl alcohol; found by analysis—36.56, 48.23, 51.09, 52.23, and 99.82% *p*-bromobenzyl alcohol.

***m*-Nitrobenzyl and Benzyl Alcohols.**—A mixture of these alcohols was analyzed as indicated above for mixtures of *m*-nitrobenzyl and furfuryl alcohols.

Benzyl and Anisyl Alcohols.—The composition of a mixture of these alcohols was determined by the procedure described above for a furfuryl-*p*-bromobenzyl alcohol mixture with the following modifications: a sample (*ca.* 2 g.) of the alcohol mixture was dissolved in 5 ml. of *p*-dioxane; 5 g. of solid potassium permanganate in addition to the 100 ml. of saturated solution was added; the final acidification was made with 25 ml. of dilute sulfuric acid (1:1); after a sample of mixed acids had been dried in a vacuum desiccator for 2 days, it was pulverized and returned to the desiccator for 2 days; and the total acidity of the sample was determined by titration. From this value, the composition (benzoic acid: *p*-anisic acid) of the acid mixture was calculated; the molar ratio of alcohols was the same as the molar ratio of acids.

The following results were observed with mixtures of the two alcohols of known compositions: mixtures as prepared—46.14 and 63.44% anisyl alcohol; found by analysis—46.39 and 62.63% anisyl alcohol.

Furfuryl and Anisyl Alcohols.—The composition of a mixture of these alcohols obtained from a reaction mixture was determined by the procedure described above for a furfuryl-*p*-bromobenzyl alcohol mixture with the following modification: the alcohol mixture isolated from the reaction mixture was distilled under reduced pressure in an atmosphere of nitrogen. Following oxidation of a weighed sample of a furfuryl alcohol–anisyl alcohol mixture, the amount of *p*-anisic acid in the final residue was determined by titration; and from this value, the composition of the alcohol mixture was calculated.

Results with mixtures of known compositions were as follows: mixtures as prepared—53.45, 53.46, 74.29, 79.25, and 100% anisyl alcohol; found by analysis—52.69, 56.06, 76.72, 77.03, and 99.47% anisyl alcohol.

Crossed Cannizzaro Reactions. General.—These reactions were carried out as much as possible according to the method used for the reaction with furfural-benzaldehyde mixtures.[3] Except in the case of furfuryl-anisyl alcohol mixtures, the alcohol pairs isolated from reaction mixtures were not distilled prior to analysis; other deviations from the furfural-benzaldehyde reaction procedure are listed below, and the results from the several reactions are summarized in Table I.

***m*-Nitrobenzaldehyde and Furfural.**—Because the rate of reaction of this mixture of aldehydes with 33% sodium hydroxide solution is very rapid, the sealed-flask technique was not practicable. The reaction was carried out with 30.2 g. (0.2 mole) of *m*-nitrobenzaldehyde, 19.2 g. (0.2 mole)

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[15] The difference between the molecular weights of benzoic acid and *p*-anisic acid permitted the use of this method of analysis; see the earlier report[3] for details.

[16] This sample was treated with hot alkaline potassium permanganate solution prior to the determination of total acidity.

of furfural, and 40 ml. of 33% sodium hydroxide solution in a three-necked flask fitted with a thermometer, a mechanical stirrer, an inlet tube for nitrogen, and a small exit passage for gas. *m*-Nitrobenzaldehyde was dissolved in furfural by gently warming the mixture, and this solution was added to the sodium hydroxide solution in the flask cooled in an ice bath at such a rate that the temperature of the reaction mixture did not rise above 45°; this required 15–20 min. The mixture was semisolid by the time all of the aldehyde solution had been added even though constant stirring had been maintained. The ice bath was replaced by a 40–45° water bath. Stirring was continued, and 20 ml. of water was added in small amounts over a period of 1 hr. Thereafter, the mixture was permitted to stand for 2 hr. before separation of reaction products was undertaken.

Furfural and *p*-Bromobenzaldehyde.—For reactions 3 and 4, 4.8 g. (0.05 mole) of furfural, 9.23 g. (0.05 mole) of *p*-bromobenzaldehyde, and 5 ml. of 33% sodium hydroxide solution were used; for reaction 5, twice the foregoing amounts were used. Ethereal solutions of alcohol mixtures were dried with anhydrous sodium sulfate; thereafter, most of the ether was removed by distillation through a 50-cm. Vigreux column, and the last traces of the solvent were removed at reduced pressure (*ca.* 18 mm.), in an atmosphere of nitrogen, from a Claisen flask with a 25-cm. column. Ethereal solutions of acids were washed with water (3 × 25 ml.); the major portion of ether was removed by distillation through a 50-cm. Vigreux column.

***m*-Nitrobenzaldehyde and Benzaldehyde.**—The same molar quantities of materials and the same procedures as those recorded above for *m*-nitrobenzaldehyde–furfural mixtures were used for the reations with this mixture of aldehydes.

Benzaldehyde and *p*-Anisaldehyde.—Because the reaction rate for this mixture of aldehydes with aqueous alkali was extremely slow, some methanol was introduced to overcome the difficulty. The reaction was carried out with 21.2 g. (0.2 mole) of benzaldehyde, 27.2 g. (0.2 mole) of *p*-anisaldehyde, and 9 g. of sodium hydroxide dissolved in 13.5 ml. of water and 5.7 ml. of methanol.

Furfural and *p*-Anisaldehyde.—With 19.2 g. (0.2 mole) of furfural, 27.2 g. (0.2 mole) of *p*-anisaldehyde, and 40 ml. of 33% sodium hydroxide solution, the reaction was carried out as described above for mixtures of furfural and *p*-bromobenzaldehyde. The alcohol mixture was distilled at reduced pressure (2 mm.) prior to analysis.

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Aluminum Chloride-Induced Isomerization of Chlorinated Biphenyls[1]

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Chlorinated biphenyls were found to isomerize in the presence of hydrogen chloride and aluminum chloride. The transformation appears to be intramolecular with phenyl migration predominating over chlorine migration.

In the course of related work[2] we observed the various chlorinated biphenyls to be readily isomerized in the presence of aluminum chloride. Since only halobenzene[3] and halonaphthalene[4–6] isomerizations have been reported in the literature, we decided to examine the chlorinated biphenyl system in more detail.

Results and Discussion

We observed that the three monochlorobiphenyls upon treatment with hydrogen chloride and aluminum chloride at 160° gave the same, presumably thermodynamic, mixture described in example 1, Table I. This isomeric distribution agrees fairly well with the thermodynamic distribution reported for other aromatic systems.[7] The results were particularly interesting when we discovered appreciable isomerization rates at temperatures as low as 100°.

TABLE I

	Compound	Conditions	Products		
			% *o*	% *m*	% *p*
(1)	*o*, *m* or *p*-Chlorobiphenyl	160°, 30 min.	3[a]	64	33
(2)	*o*-Chlorobiphenyl	100°, 15 min.	82[b]	18	<1
(3)	*p*-Chlorobiphenyl	100°, 15 min.	0.2[c]	14.8	85
(4)	*m*-Chlorobiphenyl	100°, 10 min.	3[d]	90	7
(5)	*o*-Bromobiphenyl	50°, 5 min.	69[e]	2	29

[a] Product contains 3 to 6% biphenyl. [b] Contains trace biphenyl. [c] Contains 1% biphenyl. [d] Contains trace biphenyl. [e] Contains 20% biphenyl.

We first sought to establish experimentally the inter- or intramolecular character of the transformation. To accomplish this the three monochlorobiphenyls were isomerized under very mild conditions for a short period of time. This allowed

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