

[CONTRIBUTION FROM THE DEPARTMENT OF CHEMISTRY, THE UNIVERSITY OF TEXAS, AUSTIN 12, TEXAS]

## Alkylbenzenes. XV. Friedel-Crafts Alkylations of *p*-Xylene and Mesitylene with Propyl Halides. Concurrent Rearrangements and Reorientations

BY ROYSTON M. ROBERTS AND DEP SHIENGTHONG<sup>1</sup>

RECEIVED FEBRUARY 24, 1964

A study was made of the products from alkylation of *p*-xylene and mesitylene with *n*-propyl and isopropyl halides with aluminum halide catalysts at different temperatures. At low temperatures *p*-xylene and *n*-propyl chloride gave 73% 2-*n*-propyl-*p*-xylene and 27% 2-isopropyl-*p*-xylene; at room temperature and above an isomer resulting from methyl reorientation, 5-isopropyl-*m*-xylene, was produced. *p*-Xylene and isopropyl chloride gave 2-isopropyl-*p*-xylene (62%) and 5-isopropyl-*m*-xylene (38%) at 50°. Mesitylene and *n*-propyl chloride reacted very slowly at low temperatures; the product was mainly *n*-propylmesitylene. At 30°, 5-isopropylpseudocumene and 5-isopropylhemimellitene were found, in addition to *n*-propylmesitylene; at 50 and 70°, these methyl-reorientated isopropyl isomers were the major products. No more than traces of isopropylmesitylene were found in any experiments. Reaction of isopropyl chloride with mesitylene gave isopropylmesitylene, 5-isopropylpseudocumene, and 5-isopropylhemimellitene; at 30° and above, the latter two isomers predominated. Competitive reaction of benzene and mesitylene with *n*-propyl chloride gave isopropylbenzene and *n*-propylmesitylene. Competitive reaction of benzene and mesitylene with isopropyl chloride gave isopropylbenzene, diisopropylbenzene, etc. Transalkylations between *n*-propylmesitylene and benzene and between *n*-propylbenzene and mesitylene were insignificant under conditions employed in the alkylations; transalkylations between isopropylmesitylene and benzene took place, but to a limited extent. The proportions of *n*-propyl-*p*-xylene and *n*-propylmesitylene produced by alkylations with *n*-propyl chloride are in close agreement with predictions of Smoot and Brown. However, the reorientations accompanying the alkylations and the products from competitive alkylations point to steric effects which play an important part in determining the product distribution of the alkylations.

### Introduction

Although rearrangements of alkyl groups have been known to accompany alkylations almost from the time of discovery of Friedel-Crafts reactions,<sup>2</sup> the exact mechanism of these rearrangements is still in doubt. Interest in this subject continues because of the intimate relationship between the mechanism of these rearrangements and the mechanism of the Friedel-Crafts alkylations themselves.

The first widely-accepted mechanism described the rearrangement in terms of the intermediate formation of a carbonium ion, which may either attack an aromatic nucleus directly or rearrange to a more stable carbonium ion, which may then attack an aromatic nucleus.<sup>3</sup> This was later modified by the identification of the rearranging species as a complex of the alkyl halide and the Lewis acid catalyst.<sup>4</sup> In both the original and the modified mechanisms, the rearrangement was considered to precede attachment of the alkyl moiety to the arene. However, recent data from rearrangements accompanying alkylations with alcohols and boron fluoride<sup>5</sup> and with alkyl bromides and aluminum bromide<sup>6</sup> have been interpreted as evidence of involvement of the arene with the rearranging species.

The present work represents a continuation of our interest in the effect of reaction conditions and of molecular structure on rearrangements accompanying Friedel-Crafts alkylations. In previous research,<sup>7</sup> we determined the amounts of isopropylbenzene and *n*-propylbenzene produced by alkylation of benzene with *n*-propyl chloride and aluminum chloride at several temperatures.<sup>8</sup> We were next interested in ascertaining the effect of variation in structure of the arene on the

extent of rearrangement of the alkyl group. Smoot and Brown<sup>4</sup> calculated the proportions of *n*-propyl- and isopropylarene isomers expected from alkylation of various methyl-substituted benzenes with *n*-propyl bromide and gallium bromide and reported the experimental values found with toluene, which were in good agreement with those calculated. We have now examined the aluminum chloride catalyzed reactions of *n*-propyl and isopropyl halides with *p*-xylene, mesitylene, and benzene-mesitylene mixtures. This paper reports results of these studies and conclusions that may be drawn from them regarding electronic and steric effects of methyl substituents on the benzene ring on the course of alkylations and rearrangements.

### Experimental

**Materials.**—*m*-Xylene, *p*-xylene, 2-bromo-*p*-xylene, mesitylene, pseudocumene, durene, *n*-propyl bromide, isopropyl chloride, propionic acid, and *n*-propyl alcohol were either Eastman Organic Chemicals or Matheson Coleman and Bell, best grade, and were pure according to v.p.c. analysis, except for mesitylene, which contained 9% pseudocumene. Aluminum chloride was Matheson Coleman and Bell anhydrous, purified, powder, used as received. Aluminum bromide was Matheson Coleman and Bell, technical; it was distilled at atmospheric pressure and a center cut, b.p. 250–260°, was taken.

*n*-Propyl chloride was prepared from the alcohol by means of thionyl chloride and pyridine. The product contained no isopropyl chloride (infrared and v.p.c. analysis).

**Synthesis of Authentic Propylxylenes and Propyltrimethylbenzenes.**—These compounds were synthesized by the unequivocal methods outlined below. Yields are not included since emphasis was on purity rather than quantity. Products were pure according to infrared and/or v.p.c. analysis except as specified below.

**2-*n*-Propyl-*p*-xylene.**—*p*-Xylene, propionyl chloride, aluminum chloride in carbon disulfide: 2-propionyl-*p*-xylene. Reduction by (a) zinc and hydrochloric acid and (b) hydrogen with palladium-on-carbon in acetic acid containing perchloric acid<sup>9</sup>: 2-*n*-propyl-*p*-xylene, b.p. 203–204°.

(8) Only a small temperature effect on the *n*-propylisopropylbenzene product ratio was found in this work; however, it has been aptly pointed out<sup>5</sup> that the product ratios are not intrinsic to the alkylation alone, since secondary alkylbenzenes are much more susceptible to dealkylation than primary isomers.

(9) R. M. Roberts, G. A. Ropp, and O. K. Neville, *J. Am. Chem. Soc.*, **77**, 1764 (1955).

(1) Taken from the Ph.D. dissertation of D. Shienghong, The University of Texas, Jan., 1963. Presented at the 146th National Meeting of the American Chemical Society, Denver, Colo., Jan. 19–24, 1964.

(2) G. Gustavson, *Ber.*, **11**, 1251 (1878).

(3) C. C. Price, *Chem. Rev.*, **29**, 37 (1941).

(4) C. R. Smoot and H. C. Brown, *J. Am. Chem. Soc.*, **78**, 6249 (1956).

(5) A. Streitwieser, Jr., W. D. Schaeffer, and S. Andreades, *ibid.*, **81**, 1113 (1959).

(6) S. H. Sharman, *ibid.*, **84**, 2945 (1962).

(7) R. M. Roberts and D. Shienghong, *ibid.*, **82**, 732 (1960);

**2-Isopropyl-*p*-xylene.**—2-Bromo-*p*-xylene, magnesium, acetone: dimethyl-(2,5-dimethylphenyl)carbinol. Reduction of crude carbinol by hydrogen with platinum oxide in acetic acid: 2-isopropyl-*p*-xylene, b.p. 195–196°.

**5-Isopropyl-*m*-xylene.**—The method of Nightingale and Carton<sup>10</sup> gave a mixture which was 93% 5-isopropyl-*m*-xylene and 7% 4-isopropyl-*m*-xylene (v.p.c. analysis) after careful fractional distillation, b.p. 194.5°.

**5-*n*-Propyl-*m*-xylene.**—Mesitylene, *N*-bromosuccinimide in carbon tetrachloride<sup>11,12</sup>; 3,5-dimethylbenzyl bromide. Reaction with ethylmagnesium bromide: 5-*n*-propyl-*m*-xylene, b.p. 200–202°; after two distillations, 96% pure (v.p.c.)

***n*-Propylmesitylene.**—Mesitylene, propionyl chloride, aluminum chloride, petroleum ether<sup>13</sup>; propionylmesitylene. Reduction by lithium aluminum hydride<sup>14</sup> to carbinol; hydrogenation with palladium-on-carbon in acetic acid containing perchloric acid<sup>9</sup>: *n*-propylmesitylene, b.p. 224–226°.

*Anal.* Calcd. for C<sub>12</sub>H<sub>18</sub>: C, 88.89; H, 11.11. Found: C, 89.13; H, 10.83.

**Isopropylmesitylene. A.**—Mesitylene, acetyl chloride, aluminum chloride, carbon disulfide: acetomesitylene. Reduction by lithium aluminum hydride<sup>14</sup>; methylmesitylcarbinol. Reaction with dry hydrogen chloride in ether: crude carbinol chloride. Reaction with methylmagnesium iodide: isopropylmesitylene, b.p. 220°, *n*<sub>D</sub><sup>20</sup> 1.5095.

*Anal.* Calcd. for C<sub>12</sub>H<sub>18</sub>: C, 88.89; H, 11.11. Found: C, 88.46; H, 11.03.

**B.**—Dimethylmesitylcarbinol was prepared by the method of Adams and Ferretti.<sup>15</sup> Reduction by hydrogen with palladium-on-carbon in acetic acid containing perchloric acid gave isopropylmesitylene, b.p. 220–220.5°; infrared spectrum and elementary analysis were identical with those of the product from method A.

**5-*n*-Propylpseudocumene.**—Pseudocumene, propionyl chloride, aluminum chloride, carbon disulfide: 5-propionylpseudocumene. Reduction by hydrogen with palladium-on-carbon in acetic acid containing perchloric acid<sup>9</sup>: 5-*n*-propylpseudocumene, b.p. 224–226°.

*Anal.* Calcd. for C<sub>12</sub>H<sub>18</sub>: C, 88.89; H, 11.11. Found: C, 89.02; H, 11.10.

**5-Isopropylpseudocumene.**—Pseudocumene was sulfonated in the 5-position by the method of Smith and Cass,<sup>16</sup> converted to the bromide,<sup>17</sup> and the Grignard reagent, which was allowed to react with acetone to yield the carbinol. Reduction of crude carbinol by hydrogen with platinum oxide in acetic acid gave 5-isopropylpseudocumene, b.p. 218–220°. Dehydration followed by hydrogenation with palladium-on-carbon in ethanol gave a product identical in infrared spectrum and v.p.c. retention time.

*Anal.* Calcd. for C<sub>12</sub>H<sub>18</sub>: C, 88.89; H, 11.11. Found: C, 87.89; H, 10.93.

**5-*n*-Propylhemimellitene.**—Propionylmesitylene and 5-propionylpseudocumene were both isomerized to 5-propionylhemimellitene by Baddeley's method.<sup>18</sup> The ketone was hydrogenated by the method described for 5-*n*-propylpseudocumene (above): 5-*n*-propylhemimellitene, b.p. 228–230°.

*Anal.* Calcd. for C<sub>12</sub>H<sub>18</sub>: C, 88.89; H, 11.11. Found: C, 88.85; H, 11.05.

**5-Isopropylhemimellitene.**—Acetomesitylene and 5-acetopseudocumene were both isomerized to 5-acetohemimellitene by Baddeley's method.<sup>18</sup> The ketone reacted with methylmagnesium iodide to give the carbinol, which was reduced with hydrogen and platinum oxide in acetic acid as before: 5-isopropylhemimellitene, b.p. 222–223°.

*Anal.* Calcd. for C<sub>12</sub>H<sub>18</sub>: C, 88.89; H, 11.1. Found: C, 89.07; H, 11.22.

**Synthesis of Authentic Isodurene.**—The method of Smith, Adams, and Moyer<sup>19</sup> was followed. The product, b.p. 197–198°, after five distillations, was pure (v.p.c.) and its infrared spectrum was identical with that reported by A.P.I. Project No. 44.

(10) D. Nightingale and B. Carton, *J. Am. Chem. Soc.*, **62**, 280 (1940).

(11) M. Weiler, *Ber.*, **33**, 339 (1900).

(12) R. G. Kadesch, *J. Am. Chem. Soc.*, **66**, 1207 (1944).

(13) A. Klages, *Ber.*, **35**, 2245 (1902).

(14) R. F. Nystrom and W. G. Brown, *J. Am. Chem. Soc.*, **69**, 1197 (1947).

(15) R. Adams and A. Ferretti, *ibid.*, **83**, 2561 (1961).

(16) L. I. Smith and O. W. Cass, *ibid.*, **54**, 1606 (1932).

(17) L. I. Smith and M. A. Kiess, *ibid.*, **61**, 284 (1939).

(18) G. Baddeley and A. G. Pendleton, *J. Chem. Soc.*, 807 (1952); G. Baddeley and S. Varma, *ibid.*, 2727 (1957).

(19) T. B. Johnson and W. W. Hodge, *J. Am. Chem. Soc.*, **35**, 1021 (1913).

**Analytical Methods.**—A Beckman IR5A spectrophotometer equipped with sodium chloride optics was used for infrared analysis. Quantitative measurements were made in 2,2,4-trimethylpentane solutions, as described previously.<sup>20</sup> Spectra of authentic propyldimethyl- and propyltrimethylbenzenes are reproduced in the dissertation of D. S.

Vapor-phase chromatographic (v.p.c.) analysis was made by means of a Beckman GC2A instrument equipped with a disk integrator, using a 0.25 in. × 6 ft. column packed with 30% silicone gum rubber on diatomaceous earth.

Nuclear magnetic resonance (n.m.r.) spectra were determined with a Varian Model A-60 instrument, using tetramethylsilane as an internal standard.

Both qualitative and quantitative analysis of mixtures of propyldimethylbenzenes could be made satisfactorily by means of infrared and/or v.p.c. However, the propyltrimethylbenzenes were not volatile enough for convenient v.p.c. analysis. Infrared analysis was satisfactory for the three isopropyltrimethylbenzene isomers obtained from isopropyl chloride and mesitylene, but the mixtures of up to six isomers obtained from *n*-propyl chloride and mesitylene defied quantitative infrared analysis because of the overlap of characteristic absorptions. Nuclear magnetic resonance analysis of the isopropyltrimethylbenzene mixtures nicely confirmed the infrared analysis; in the case of the mixtures from *n*-propyl chloride, it was invaluable. Although we did not feel that the data justified numbers in Table III the n.m.r. spectra were sufficiently distinctive to indicate clearly which isomers were present in appreciable amount and in what order of abundance. The infrared and n.m.r. spectra of the six authentic propyltrimethylbenzene isomers and of the eight mixtures of Table III are on file at The University of Texas, and are described in the dissertation of D. S.

**Alkylations. A. *p*-Xylene by *n*-Propyl Halides.**—*p*-Xylene and anhydrous aluminum chloride or bromide were mixed in a 250-ml. three-necked flask which was equipped with a reflux condenser, mechanical stirrer, and dropping funnel. A drying tube filled with calcium chloride was attached to the reflux condenser. The temperature of the reaction flask was controlled within ±1° by means of an ice bath, a water bath, or an electrically heated oil bath. The *n*-propyl halide was added dropwise after stirring was begun. At the end of the addition and reaction time the reaction mixture was cooled (when necessary) and added to a mixture of ice and water. After stirring until decomposition was complete, the organic layer was separated, washed with sodium bicarbonate solution and water, and dried over sodium sulfate. Samples of this crude product were analyzed by v.p.c. The main part was distilled through a 100-cm. vacuum-jacketed Nichrome spiral column with total reflux and controlled take-off. Distillation cuts were taken at (a) ambient–140°, (b) 140–195°, (c) 195–200°, and (d) 200–207°. Cuts b, c, and d were analyzed by v.p.c. and infrared absorption. Some of the low-temperature reaction mixtures were analyzed only by v.p.c., without distillation.

Details of conditions and results of twelve experiments are given in Table I.

**B. *p*-Xylene by Isopropyl Chloride.**—These alkylations were carried out in the same way as those with *n*-propyl halides, except that in the distillation different arbitrary cuts were taken: (a) ambient–140°, (b) 140–190°, (c) 190–195°, and (d) 195–200°. Details of conditions and results of seven experiments are given in Table II.

**C. Mesitylene by *n*-Propyl Halides.**—Alkylations by *n*-propyl chloride were carried out as with *p*-xylene. The trimethylpropylbenzene mixtures boiling at about 218–228° were analyzed by infrared and n.m.r. spectrometry. Details of conditions and results of eight experiments are given in Table III.

Several reactions of *n*-propyl bromide with mesitylene catalyzed by aluminum bromide were carried out at 10°, with reaction times of 16–60 min. Yields of trimethylpropylbenzenes (mainly *n*-propylmesitylene) were calculated from v.p.c. analysis, using 2-*n*-propyl-*p*-xylene as an internal standard. The yields, based on *n*-propyl bromide, were 9–12%.

**D. Mesitylene by Isopropyl Chloride.**—These alkylations were carried out as with *p*-xylene. The trimethylbenzene mixtures boiling at about 215–220° were analyzed by infrared and n.m.r. spectrometry. Details of conditions and results of ten experiments are given in Table IV.

(20) R. M. Roberts, Y. W. Han, C. H. Schmid, and D. A. Davis, *ibid.*, **81**, 640 (1959).

TABLE I  
REACTIONS OF *n*-PROPYL HALIDES WITH *p*-XYLENE (0.50 MOLE)

<i>n</i> -PrX, X	Temp., °C.	Time, <sup>a</sup> hr.	Yield, <sup>b</sup> %	Products, <sup>c</sup> %		
				2- <i>i</i> -Pr- <i>p</i> -xylene	2- <i>n</i> -Pr- <i>p</i> -xylene	5- <i>i</i> -Pr- <i>m</i> -xylene
Cl <sup>d</sup>	-17	2	19	27	73	..
Cl <sup>d</sup>	0	2	39	34	66	..
Cl <sup>d</sup>	10	2	51	38	62	Tr.
Cl <sup>d</sup>	30	2	55	41	54	5
Cl <sup>d</sup>	50	2	68	31	53	16
Cl <sup>d</sup>	10	1	45	38	62	..
Cl <sup>d</sup>	10	5	61	40	60	..
Cl <sup>e</sup>	10	2	50	37	63	..
Cl <sup>f</sup>	14	1	57	31	69	..
Br <sup>g</sup>	10	2	28	25	75	..
Br <sup>h</sup>	14	1	55	24	76	..
Br <sup>h</sup>	14	5 min.	38	22	78	..

<sup>a</sup> Total time before work-up; time for addition of PrX to *p*-xylene and catalyst was about half this time. <sup>b</sup> Combined yield of propylxylenes, based on PrX. <sup>c</sup> Distribution of isomers calcd. from infrared and v.p.c. analyses. <sup>d</sup> 0.25 mole and AlCl<sub>3</sub>, 0.025 mole. <sup>e</sup> 0.25 mole and AlCl<sub>3</sub>, 0.075 mole. <sup>f</sup> 0.13 mole and Al<sub>2</sub>Br<sub>6</sub>, 0.013 mole. <sup>g</sup> 0.16 mole and AlCl<sub>3</sub>, 0.025 mole. <sup>h</sup> 0.13 mole and Al<sub>2</sub>Br<sub>6</sub>, 0.013 mole.

TABLE II  
REACTIONS OF ISOPROPYL CHLORIDE (0.25 MOLE) WITH *p*-XYLENE (0.50 MOLE) AND ALUMINUM CHLORIDE (0.025 MOLE)

Temp., °C.	Time, <sup>a</sup> hr.	Yield, <sup>b</sup> %	Products, <sup>c</sup> %	
			2- <i>i</i> -Pr- <i>p</i> -xylene	5- <i>i</i> -Pr- <i>m</i> -xylene
0	2	53	100	..
0	5	43	100	..
0 <sup>d</sup>	2	48	95	5
10	2	60	100	..
30	2	66	81	19
50	2	66	62	38
70	2	58	48	52

<sup>a</sup> Total time before work-up; time for addition of *i*-PrCl to *p*-xylene and AlCl<sub>3</sub> was about half this time. <sup>b</sup> Combined yield of propylxylenes, based on *i*-PrCl. <sup>c</sup> Distribution of isomers calcd. from infrared and v.p.c. analyses. <sup>d</sup> Triple amount of AlCl<sub>3</sub> used in this experiment.

**Competitive Reactions of Benzene and Mesitylene with *n*-Propyl Chloride.**—A mixture of 60 g. (0.50 mole) of mesitylene, 40 g. (0.52 mole) of benzene, and 3.3 g. (0.025 mole) of aluminum chloride was maintained at 35° while 20 g. (0.26 mole) of *n*-propyl chloride was added during 2.5 hr. The mixture was stirred for an additional 2.5 hr. and then decomposed and worked up as usual. Distillation cuts at (a) ambient–80°, (b) 80–150°, (c) 150–160°, (d) 160–165°, (e) 165–220°, and (f) 220–226° were taken. Cuts c–f were analyzed by v.p.c. and cut f by infrared. The products were isopropylbenzene (27%, based on *n*-propyl chloride) and propylmesitylenes (26%). The propylmesitylenes were about 99% *n*-propyl- and 1% isopropylmesitylene.

A second experiment was performed, identical with the preceding except that the mole ratio of benzene to mesitylene was 3:1 and the total reaction time was only 2 hr. The products were isopropylbenzene (18%) and propylmesitylenes (8%), 99% *n*-propyl- and 1% isopropylmesitylene.

**Competitive Reactions of Benzene and Mesitylene with Isopropyl Chloride.**—Reaction of 30 g. (0.25 mole) of mesitylene, 20 g. (0.26 mole) of benzene, 3.3 g. (0.025 mole) of aluminum chloride, and 20 g. (0.26 mole) of isopropyl chloride at 30° for 5 hr. (2.5 hr. allowed for addition of isopropyl chloride) gave a mixture of products which were found by v.p.c. and infrared analysis to consist of isopropylbenzene (39%, based on isopropyl chloride), diisopropylbenzene (16%), and triisopropylbenzene (1%). Traces of isopropylmesitylene and/or 5-isopropylpseudocumene were present in the pot residue from the distillation.

**Reorientations of Alkylbenzenes. A. *p*-Xylene.**—A mixture of *p*-xylene (0.25 mole) and aluminum chloride (0.013 mole) was stirred at 30° for 2 hr. The mixture was decomposed and worked up in the same way as those from alkylations. Analysis by v.p.c. of the organic mixture showed it to consist of benzene (2%), tol-

uene (2%), xylenes (94%), and pseudocumene (2%); infrared analysis showed the xylenes to be 99% *para* and 1% *meta*.

A second experiment identical with the above except that the reactants were heated at 50° gave the following mixture of hydrocarbons: benzene (12%), toluene (10%), xylenes (70%), mesitylene (1%), and pseudocumene (7%); the xylene fraction was 89% *para*, 9% *meta*, and 2% *ortho*.

**B. Mesitylene.**—A mixture of mesitylene (0.25 mole, containing 9% pseudocumene as an impurity) and aluminum chloride (0.013 mole) was stirred at 30° for 4 hr. After treatment of the reaction mixture as usual, it was analyzed by v.p.c., which showed no reorientation had occurred; *i.e.*, the composition was still 91% mesitylene, 9% pseudocumene.

A mixture heated at 50° for 2 hr. gave about 2% reorientation; *i.e.*, the composition of the reaction mixture was 89% mesitylene, 11% pseudocumene, with a trace of toluene present.

A mixture heated at 70° for 4 hr. gave 79% mesitylene, 11% pseudocumene, 2% toluene, 3% xylenes, and 5% tetramethylbenzenes.

**C. Isodurene.**—A mixture of isodurene (0.11 mole) and aluminum chloride (0.0056 mole) was stirred at 30° for 2 hr. After treatment of the reaction mixture as usual, it was fractionally distilled and analyzed by v.p.c. and infrared spectrometry. The hydrocarbon mixture contained toluene (trace), xylenes (trace), mesitylene (1%), pseudocumene (trace), hemimellitene (1%), isodurene (90%), durene (6%), pentamethylbenzene (2%), and hexamethylbenzene (trace).

A reaction at 50° for 2 hr. gave toluene (trace), xylenes (trace), mesitylene (2%), pseudocumene (trace), hemimellitene (2%), isodurene (85%), durene (7%), pentamethylbenzene (4%), and hexamethylbenzene (trace).

A reaction at 70° for 2 hr. gave toluene (trace), xylenes (1%), mesitylene (3%), pseudocumene (1%), hemimellitene (2%), isodurene (79%), durene (7%), pentamethylbenzene (6%), and hexamethylbenzene (trace).

Penta- and hexamethylbenzene were found in the distillation residues, the latter being obtained in crystalline form.

**D. *n*-Propylmesitylene.**—A mixture of *n*-propylmesitylene (0.062 mole) and aluminum chloride (0.0031 mole) was stirred at 30° for 5 hr. After decomposition and treatment as usual the reaction mixture was distilled and analyzed by v.p.c. and infrared spectrometry. The recovered hydrocarbon fraction consisted of *n*-propylmesitylene (96%) and mesitylene (4%).

When 0.062 mole of *n*-propylmesitylene and 0.011 mole of aluminum chloride was stirred at 50° for 4 hr. the mixture of hydrocarbons produced was mesitylene (1%), pseudocumene (2%), 5-*n*-propyl-*m*-xylene (9%), 4-*n*-propyl-*o*-xylene (2%), *n*-propylmesitylene (53%), 5-*n*-propylpseudocumene (24%), and 5-*n*-propylhemimellitene (9%).

**E. Isopropylmesitylene.**—A mixture of isopropylmesitylene (0.0617 mole) and aluminum chloride (0.0034 mole) was stirred at 50° for 4 hr. After decomposition and treatment in the usual way, the reaction mixture was distilled and analyzed by v.p.c. and infrared spectrometry. The mixture of hydrocarbons consisted of mesitylene (2%), pseudocumene (5%), isopropylxylenes (18%), isopropylmesitylene (9%), 5-isopropylpseudocumene (38%), and 5-isopropylhemimellitene (28%).

**Transalkylations.**—A mixture of *n*-propylmesitylene (0.060 mole), benzene (0.060 mole), and aluminum chloride (0.0060 mole) was stirred at 35° for 5 hr. After decomposition with water, the reaction mixture was distilled and analyzed by infrared and v.p.c. Only starting materials were found. Similar results were obtained with *n*-propylbenzene, mesitylene, and aluminum chloride.

A mixture of isopropylmesitylene (0.015 mole), benzene (0.15 mole), and aluminum chloride (0.0015 mole) was stirred at 30° for 5 hr. After decomposition with water, the reaction mixture was distilled and analyzed by infrared and v.p.c. The material boiling above benzene consisted of isopropylbenzene (5%), mesitylene (13%), and isopropyltrimethylbenzene (82%).

## Results

**Propylations of *p*-Xylene. A. By *n*-Propyl Halides.**—Reaction of *n*-propyl chloride and aluminum chloride at temperatures from -17° to 50° gave 2-*n*-propyl-*p*-xylene as the major product (Table I). The highest proportion of *n*-propyl isomer (73%) was obtained at the lowest temperature, as expected. The proportion

TABLE III

REACTIONS OF *n*-PROPYL CHLORIDE (0.25 MOLE) WITH MESITYLENE<sup>a</sup> (0.50 MOLE) AND ALUMINUM CHLORIDE (0.025 MOLE)

Temp., °C.	Time, <sup>b</sup> hr.	Yield, <sup>c</sup> %	Products, <sup>d</sup> %					
			<i>n</i> -PrMes <sup>e</sup>	<i>i</i> -PrMes	<i>n</i> -PrPsc <sup>f</sup>	<i>i</i> -PrPsc	<i>n</i> -PrHmm <sup>g</sup>	<i>i</i> -PrHmm
0	2	3	XXX	...	...	...	...	...
0	12	6	XXX	Tr.	...	Tr.	...	...
10	12	11	XXX	...	Tr.	X	...	...
30	4	40	XXX	...	Tr.	XX	...	Tr.
30 <sup>h</sup>	4	28	XX	Tr.	...	XX	...	X
30 <sup>i</sup>	4	53	XX	...	...	X	...	XX
50	2	47	X	...	?	XX	?	X
70	2	27	X	...	?	XXX	?	XX
70	4	23	X	...	Tr.	XX	Tr.	XXX

<sup>a</sup> The starting material contained 9% pseudocumene. <sup>b</sup> Total time before work-up. Time for addition of *n*-PrCl to mesitylene and AlCl<sub>3</sub> was 2 hr. in first two expt., 1 hr. in all others. <sup>c</sup> Combined yield of trimethylpropylbenzenes, based on *n*-PrCl. <sup>d</sup> Approximate distribution of isomers calcd. from n.m.r. (and infrared): XXX indicates largest amount of a given isomer; XX, smaller amount; X, still smaller amount; Tr. indicates trace amount (less than 10%). <sup>e</sup> *n*-Propylmesitylene. <sup>f</sup> 5-*n*-Propylpseudocumene. <sup>g</sup> 5-*n*-Propylhemimellitene. <sup>h</sup> Double amount of AlCl<sub>3</sub> used in this experiment. <sup>i</sup> Ten times amount of AlCl<sub>3</sub> used in this experiment. <sup>j</sup> Possibly present, but no positive evidence.

TABLE IV

REACTIONS OF ISOPROPYL CHLORIDE (0.25 MOLE) WITH MESITYLENE<sup>a</sup> (0.50 MOLE) AND ALUMINUM CHLORIDE (0.025 MOLE)

Temp., °C.	Time, <sup>b</sup> hr.	Yield, <sup>c</sup> %	Products, <sup>d</sup> %		
			<i>i</i> -PrMes <sup>e</sup>	<i>i</i> -PrPsc <sup>f</sup>	<i>i</i> -PrHmm <sup>g</sup>
0	2	27	57	43	..
0	4	30	49	51	..
0 <sup>h</sup>	2	34	32	68	..
30	2	67	19	48	33
30	4	65	18	48	34
30 <sup>h</sup>	2	69	16	56	28
50	2	58	17	52	31
50	4	46	19	44	47
50 <sup>h</sup>	2	48	18	49	33
70	2	39	19	39	42

<sup>a</sup> The starting material contained 9% pseudocumene. <sup>b</sup> Total time before work-up; time for addition of isopropyl chloride to mesitylene and AlCl<sub>3</sub> was 1 hr. <sup>c</sup> Combined yield of trimethylpropylbenzenes. Pseudocumene and isopropyl-*m*-xylenes were found in all experiments at 30° and above. <sup>d</sup> Distribution of isomers calcd. from infrared (and n.m.r.) analysis. <sup>e</sup> Isopropylmesitylene. <sup>f</sup> 5-Isopropylpseudocumene. <sup>g</sup> 5-Isopropylhemimellitene. <sup>h</sup> Double amount of AlCl<sub>3</sub> used in these experiments.

at 30° (54%) was exactly that predicted by Smoot and Brown<sup>4</sup> (53.6%); however, their prediction was for products from the homogeneous reaction of *n*-propyl bromide catalyzed by gallium bromide at 25°. Besides the other expected isomer, 2-isopropyl-*p*-xylene, an isomer resulting from methyl reorientation, 5-isopropyl-*m*-xylene, was produced in the alkylations at 30 and 50°. Longer reaction times and larger amounts of catalysts had little effect on the proportion of isomers produced (at 10°).

*n*-Propyl bromide, with either aluminum chloride or bromide catalyst, gave less rearrangement (22–25% at 10–14°). *n*-Propyl chloride with aluminum bromide catalyst gave less rearrangement than with aluminum chloride; halide exchange undoubtedly occurred.<sup>21</sup>

**B. By Isopropyl Chloride.**—Reaction of isopropyl chloride and aluminum chloride at 0 and 10° gave only 2-isopropyl-*p*-xylene (Table II). However, with a larger amount of catalyst, even at 0° some methyl reorientation occurred with the formation of 5-isopropyl-*m*-xylene. At higher temperatures this reorientation became pronounced; at 70° the major product was 5-isopropyl-*m*-xylene.

**Propylations of Mesitylene. A. By *n*-Propyl Chloride.**—Preliminary experiments with these reactants indicated that not only propylmesitylenes but also propylpseudocumenes and propylhemimellitenes were produced, as a result of methyl reorientations. The presence of up to six isomers in the reaction mixtures made precise quantitative analysis difficult, but by a combination of infrared and nuclear magnetic resonance spectrometric analysis, it was possible to determine the approximate composition of mixtures as shown in Table III.<sup>22</sup> It may be seen that the major isomer produced at low temperatures (0–10°) was *n*-propylmesitylene, in low yield. Less than 10% isopropylmesitylene was formed. At 30°, the major product was still *n*-propylmesitylene, but appreciable amounts of 5-isopropylpseudocumene and traces of 5-*n*-propylpseudocumene and 5-isopropylhemimellitene were formed. At the same temperature, with double and ten times the amount of catalyst, the production of 5-isopropylpseudocumene and 5-isopropylhemimellitene was increased. At 50 and 70°, with 2-hr. reaction times, the major product was 5-isopropylpseudocumene. At 70° with a 4-hr. reaction time, the major product was 5-isopropylhemimellitene. In none of the eight experiments was more than a trace of isopropylmesitylene produced. The yields at 70° were lower than at 30 and 50°, presumably because of instability of the isopropylarenes toward dealkylation.

**B. By Isopropyl Chloride.**—Since the reaction mixtures from reaction of isopropyl chloride with mesitylene contained a maximum of three isomers, they could be analyzed more precisely; results of ten experiments are shown in Table IV. Even at 0° almost equal amounts of isopropylmesitylene and 5-isopropylpseudocumene were produced; with a doubled amount of catalyst the latter isomer predominated by more than a 2 to 1 ratio. At 30° and above, 5-isopropylhemimellitene was produced in significant amounts, actually predominating in some experiments. Isopropylmesitylene was the least abundant isomer in all alkylations conducted at temperatures above 0°.

**Competitive Reactions of Benzene and Mesitylene with Propyl Chlorides. A. *n*-Propyl Chloride.**—*n*-Propyl chloride was allowed to react with equimolar

(22) Because of serious overlap of characteristic infrared absorption peaks of propylhemimellitenes with those of propylmesitylenes and propylpseudocumenes, n.m.r. spectra were more useful than infrared for analyses of these mixtures.

(21) P. J. Trotter, *J. Org. Chem.*, **28**, 2093 (1963).

amounts of benzene and mesitylene in the presence of aluminum chloride at 35°. The products were isopropylbenzene (27%, based on the *n*-propyl chloride) and *n*-propylmesitylene (26%), containing about 1% isopropylmesitylene. A second experiment in which the mole ratio of benzene to mesitylene was 3:1 gave 18% isopropylbenzene and 8% *n*-propylmesitylene.

**B. Isopropyl Chloride.**—A similar experiment in which isopropyl chloride reacted with equimolar amounts of benzene and mesitylene at 30° gave isopropylbenzene (39%), diisopropylbenzene (16%), and triisopropylbenzene (1%) and only traces of isopropylmesitylene.

**Reorientations of Alkylbenzenes.**—Treatment of *p*-xylene with aluminum chloride in the same proportions used in the alkylations gave 1% isomerization to *m*-xylene at 30° and 9% at 50° (2 hr.). Mesitylene (containing 9% pseudocumene) showed no further reorientation at 30° after treatment with aluminum chloride for 4 hr.; after 2 hr. at 50° the composition was 89% mesitylene, 11% pseudocumene; after 4 hr. at 70° it was 79% mesitylene, 11% pseudocumene, 2% toluene, 3% xylenes, and 5% tetramethylbenzenes.

For comparison of the relative effect of a methyl group (compared to *n*-propyl and isopropyl) in causing reorientation of other methyl groups in tetraalkyl-substituted benzenes, isodurene was treated with aluminum chloride at 30, 50, and 70°. Neglecting the disproportionation which occurred, the extent of reorientation of isodurene to durene was 6.3, 7.6, and 3.2% at these three temperatures.

Treatment of *n*-propylmesitylene with aluminum chloride at 30° for 5 hr. produced no reorientation or rearrangement; a small amount of dealkylation to mesitylene occurred. Treatment at 50° for 4 hr. gave more dealkylation, disproportionation, and reorientation, but no rearrangement of *n*-propyl side chains; the proportions of *n*-propyltrimethylbenzenes were 61% *n*-propylmesitylene, 28% 5-*n*-propylpseudocumene, and 11% 5-*n*-propylhemimellitene.

Reaction of isopropylmesitylene at 50° for 4 hr. resulted in much more methyl reorientation; the recovered isopropyltrimethylbenzenes were 11% isopropylmesitylene, 51% 5-isopropylpseudocumene, and 38% 5-isopropylhemimellitene.

### Discussion of Results

The finding of an *n*-propyl:isopropyl-*p*-xylene product ratio almost exactly that predicted by Smoot and Brown<sup>4</sup> is an interesting coincidence, but probably only a coincidence. Besides the facts that the prediction was for reaction of *n*-propyl bromide instead of the chloride and for gallium bromide instead of aluminum chloride catalyst, one must consider that the basis of the prediction was the electronic effect of the methyl groups, with no allowance for steric effects.

Evidence for a steric effect between methyl and *t*-butyl groups in alkylations of toluene<sup>23</sup> and *p*-xylene<sup>24</sup> is clear-cut. We conclude that the methyl reorientations that we have observed are indicative of steric effects between methyl and isopropyl groups, since *p*-xylene and mesitylene gave little reorientation when treated with the same amount of aluminum chloride;

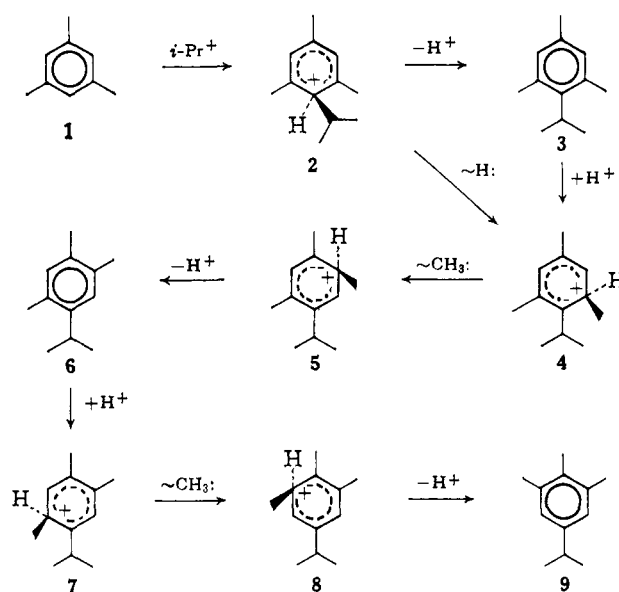


Figure 1.

*e.g.*, the methyl-reoriented, isopropylated products did not result from reorientation of *p*-xylene and mesitylene to *m*-xylene and pseudocumene, followed by isopropylation. These alkylation-induced reorientations were not so extensive in the *p*-xylene series as in the mesitylene series, but, particularly in the latter series, the preferential attachment of an *n*-propyl group between two methyl groups, due to the smaller steric requirement of the *n*-propyl group, may be a factor equally or more important than the electronic effect of the methyl groups in determining the *n*-propyl/isopropylarene product ratio.

The production of 5-isopropyl-*m*-xylene from *p*-xylene and of 5-isopropylpseudocumene and 5-isopropylhemimellitene from mesitylene in these propylations is apparently a consequence of the instability of molecules in which the isopropyl group is attached *ortho* to two, or even one, methyl group. However, it is not necessary for isopropylmesitylene, for example, to be fully formed and then isomerized to the isopropylpseudocumene and -hemimellitene isomers. As shown in Fig. 1, it is possible for the  $\sigma$ -complex 2 to undergo hydride and methyl shifts before trigonal bonding is completed. In the  $\sigma$ -complexes 2 and 4, the isopropyl group is not in the same plane with the two *o*-methyl groups as it is in 3. In 5-isopropylpseudocumene (6) the isopropyl group is *ortho* to only one methyl group and in 5-isopropylhemimellitene (9) it is *ortho* to none.

The *n*-propyl group would be expected to interfere less with *o*-methyl groups, and the experimental results were in line with this expectation; *e.g.*, little if any reorientation of *n*-propyl-*p*-xylene and *n*-propylmesitylene was observed in the alkylations.

The rate of reaction of *n*-propyl chloride with mesitylene was much lower than with benzene, judged by yields of alkylation products under identical experimental conditions. This finding at first appears anomalous in view of the theory that less rearrangement accompanies *n*-propylation of mesitylene than benzene because of the greater nucleophilicity of the former, but it does not necessarily invalidate the theory. The apparent rate of reaction of isopropyl chloride with mesitylene was slightly higher than that of *n*-

(23) M. J. Schlatter and R. D. Clark, *J. Am. Chem. Soc.*, **75**, 361 (1953).

(24) B. S. Friedman, F. L. Morrizz, C. J. Morrissey, and R. Koncos, *ibid.*, **80**, 5867 (1958).

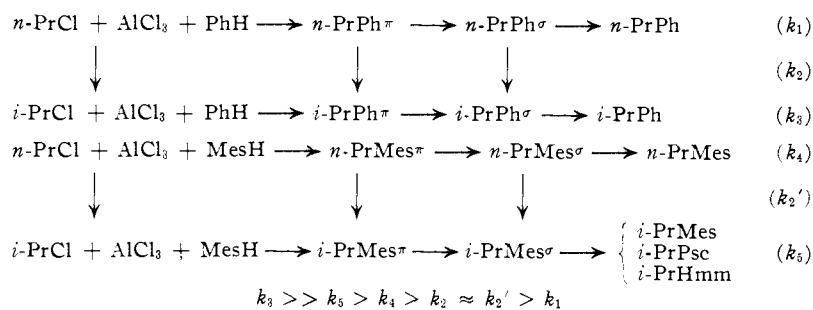


Figure 2.

propyl chloride, but it was also much lower than the rate with benzene. The explanation of the reduced rates of reaction of both propyl chlorides with mesitylene lies in the deactivation of the aluminum chloride as an alkylation catalyst by more extensive acid-base complex formation with the stronger Lewis base mesitylene than with benzene.<sup>25</sup>

A better comparison of the relative rates of alkylations of benzene and mesitylene by the propyl chlorides was sought by means of competitive alkylations. In these experiments, although the catalyst would be deactivated by complex formation with mesitylene, this should impose no preference on the reactivity of the propyl chlorides with benzene and mesitylene, both of which would be present in the reaction mixture.<sup>26</sup> Isopropyl chloride was found to react almost exclusively with benzene, showing the strong steric reluctance of the isopropyl group to combine with mesitylene. The reaction of *n*-propyl chloride with benzene-mesitylene mixtures was found to give almost equal amounts of *n*-propylmesitylene and isopropylbenzene. The isopropylbenzene found in these experiments was not produced by rapid initial reaction of isopropyl chloride with mesitylene to yield isopropylmesitylene, followed by transalkylation to benzene. In separate experiments, the extent of transfer of isopropyl groups from isopropylmesitylene to benzene was found to be too small to account for the isopropylbenzene produced in the competitive alkylations. It is interesting to note that no transfer of the *n*-propyl group between *n*-propylmesitylene and benzene or between mesitylene and *n*-propylbenzene occurred. If the transfer of a primary alkyl group follows an alkylation-dealkylation mechanism as suggested by Streitwieser and Reif,<sup>27</sup> a transfer to or from a mesitylene molecule would be expected to be difficult because of steric hindrance by the methyl substituents. Although the transfer of the isopropyl group was not extensive, it was observed. This is in accord with the theory that transalkylations of secondary groups take place by an ionizing mechanism; steric effects should be less important in this case.

A scheme which satisfactorily correlates the data on the reactions of propyl chlorides with benzene and mesitylene, separately and in mixtures, is outlined in Fig. 2.

The relative rates of alkylation of benzene by *n*-propyl bromide and isopropyl bromide (gallium bro-

mid catalyst at 25°) can be estimated as about 1:3,000<sup>4,28</sup>; the relative rates of the chlorides, with aluminum chloride catalyst, may be assumed to be at least in the same order ( $k_3 \gg k_1$ , Fig. 2). On the basis of electronic effects of methyl groups, the rate of reaction of *n*-propyl chloride with mesitylene might be expected to be about 24 times its rate with benzene<sup>4</sup> ( $k_4 > k_1$ ). However, because of the deactivation of the catalyst by mesitylene, this increased rate is not observed in separate reactions of *n*-propyl chloride with benzene and mesitylene. The rate of reaction of isopropyl chloride with mesitylene might be expected to be about 3000 times that of *n*-propyl chloride, assuming the same rate difference of the two propyl chlorides as with benzene. However, a rough estimate based on yields<sup>29</sup> from separate experiments under identical conditions indicated a much smaller rate increment of the isopropyl chloride over the *n*-propyl chloride ( $k_5 > k_4$ ).

The results from the competitive experiments are enlightening. The expected rate ratio  $k_4 > k_1$  was indeed indicated by the fact that reactions of *n*-propyl chloride with benzene-mesitylene mixtures produced *n*-propylmesitylene and virtually no *n*-propylbenzene. The other major product (isopropylbenzene) requires further explanation. Isopropylmesitylene would have been expected on the basis of electronic effects of methyl groups; *i.e.*,  $k_5/k_3$  should be *ca.* 24, but the reverse appears to be true ( $k_3 \gg k_5$ ). This indication was confirmed by the competitive reaction of isopropyl chloride with benzene-mesitylene; the products were isopropyl-, diisopropyl-, and triisopropylbenzene, with only traces of isopropylmesitylene being produced.

Thus it seems clear that the formation of *n*-propylmesitylene as the major product of alkylation of mesitylene by *n*-propyl chloride at low temperatures, either alone or in the presence of benzene, is owing to two factors: (1) the rate of reaction of mesitylene is greater than that of benzene with *n*-propyl chloride (or its complex—see below), while the rate of rearrangement of *n*-propyl chloride is little different in benzene and in mesitylene (*i.e.*,  $k_4 > k_1$ ;  $k_2 \approx k_2'^{30}$ ); (2) the rate of reaction of isopropyl chloride (or its complex—see below) with mesitylene is abnormally low, due to steric hindrance ( $k_5 \ll k_3$ ).

The first of these factors is exactly that predicted by Smoot and Brown.<sup>4</sup> The second, which may be equally important, was perhaps not foreseen.

(28) S. U. Choi and H. C. Brown, *ibid.*, **81**, 3315 (1959).

(25) Sharman<sup>6</sup> attributes reduced rates of alkylations of multiply alkylated benzenes to this same cause.

(26) The amount of aluminum chloride used was not large enough to reduce the concentration of mesitylene significantly, even if it were assumed to complex completely an equimolar amount.

(27) A. Streitwieser, Jr., and L. Reif, *J. Am. Chem. Soc.*, **82**, 5003 (1960); **86**, 1988 (1964).

(29) It should be noted that the "yields" from isopropylation include not only isopropylmesitylene but (mainly, at 30°) 5-isopropylpseudocumene and 5-isopropylhemimellitene.

(30) Since the actual rate of reaction of mesitylene with both *n*-propyl chloride and isopropyl chloride is greatly reduced by deactivation of the catalyst by mesitylene, we must assume that the deactivation of the catalyst applies to the rearrangement process as well as to the alkylation process.

Unfortunately, our results do not shed any new light on the nature of the rearranging species. As we have indicated in Fig. 2, rearrangement may occur at various stages; the rates  $k_2$  and  $k_2'$  may apply equally well to rearrangement of propyl chloride-aluminum chloride complex,  $\pi$ -complex, or  $\sigma$ -complex without changing the interpretation of the experimental results.

We do feel that our results draw new attention to the importance of steric factors in Friedel-Crafts alkylations, and to the practical effects evidenced by the re-

orientations induced in polyalkylbenzenes to relieve steric strains.

**Acknowledgment.**—We wish to thank Dr. Jeff C. Davis, Jr., for help with the nuclear magnetic resonance spectrometric analysis. Financial assistance from the National Science Foundation and the Robert A. Welch Foundation is also gratefully acknowledged. D. S. wishes to thank the Department of State, Agency for International Development, for financial aid.

[CONTRIBUTION FROM THE DEPARTMENTS OF CHEMISTRY OF THE UNIVERSITY OF HAWAII, HONOLULU, HAWAII, AND VIRGINIA POLYTECHNIC INSTITUTE, BLACKSBURG, VA.]

## Kinetics and Mechanism of Iodination of Pyrazole. Comparative Reactivities of Pyrazole and Imidazole<sup>1</sup>

BY JOHN D. VAUGHAN, DON G. LAMBERT, AND VIRGINIA L. VAUGHAN

RECEIVED FEBRUARY 24, 1964

The kinetics of iodination of pyrazole in aqueous solution has been studied. The rate was found to be separable into parallel "uncatalyzed" and buffer-catalyzed reactions. A mechanism involving attack of the conjugate base of pyrazole by iodine was given. The relative reactivities of pyrazole and imidazole in their "uncatalyzed" reactions were found to be comparable in magnitude and were discussed in mechanistic and theoretical terms.

The kinetics of iodination of aromatic nitrogen heterocycles has been reported for trisubstituted pyrroles,<sup>2</sup> imidazole,<sup>3</sup> and histidine.<sup>4</sup> The observed more rapid rate of iodination of 1-substituted pyrroles relative to pyrrole indicates that iodination probably occurs through the neutral pyrrole molecule rather than through the pyrrole anion.<sup>5</sup> In contrast, the non-reactivity of 1-substituted imidazoles suggests that the anion of imidazole undergoes iodination rather than the undissociated molecule.<sup>3a,5</sup> Similarly, the iodinations of phenol<sup>6,7</sup> and 4-nitrophenol<sup>8</sup> seem to involve attack of the anion.

Pyrazole and most substituted pyrazoles undergo iodination in the four position.<sup>9</sup> Since 1-methylpyrazole also undergoes iodination (in the four position)<sup>9</sup> De La Mare and Ridd<sup>5</sup> suggested that iodination occurs through the neutral pyrazole molecule rather than through the pyrazole anion. Brown's<sup>10</sup> molecular orbital calculations of localization energies of the pyrazole molecule and of the anion showed that the anion should be markedly more reactive to electrophilic reagents than the neutral molecule.

The purpose of the present investigation was to determine the detailed kinetics of iodination of pyrazole, and to compare the relative rates of iodination of pyrazole and imidazole under similar conditions. To provide similar conditions, it was desirable to re-examine the iodination of imidazole at higher temperatures and ionic strength than the previous study.<sup>3a</sup> This in-

vestigation revealed that pyrazole, like imidazole, appears to undergo base-catalyzed iodination through the anion, and that the relative reactivities of pyrazole and imidazole are very similar in the water-catalyzed ("uncatalyzed") reaction.

### Experimental

**Materials.**—Pyrazole (Py), obtained from Columbia Organic Chemicals Co., was recrystallized three times from cyclohexane; m.p. 68.5°. Imidazole (Im), obtained from Aldrich Chemical Co., Inc., was recrystallized three times from benzene; m.p. 88.0°. Reagent grades of KI, Na<sub>2</sub>HPO<sub>4</sub>, KH<sub>2</sub>PO<sub>4</sub>, NaNO<sub>3</sub>, and NH<sub>4</sub>NO<sub>3</sub> were dried at 110° and used without further purification. Reagent grade sublimed iodine was resublimed before use. Perchloric acid stock solution prepared from reagent grade HClO<sub>4</sub> (70%) was standardized indirectly against potassium acid phthalate.

**Product Analysis.**—The iodinated product of Py was prepared by the procedure of Hüttel, *et al.*,<sup>9</sup> except Na<sub>2</sub>HPO<sub>4</sub>-KH<sub>2</sub>PO<sub>4</sub> buffer was used instead of sodium acetate. Excess iodine was destroyed by NaHSO<sub>3</sub>. The product was recrystallized twice from cyclohexane (white needles, m.p. 112°). Hüttel, *et al.*,<sup>9</sup> reported that 4-iodopyrazole is pale yellow, m.p. 108.5°. Reimfinger, *et al.*,<sup>11</sup> prepared 3(5)-iodopyrazole, m.p. 72-73°. An n.m.r. spectrum of our product was that expected for 4-iodopyrazole.<sup>12</sup>

Ridd showed that the product of the iodination of Im with Im in stoichiometric excess is 2,4(5)-diiodoimidazole,<sup>3a</sup> with the initial substitution occurring in the 4-position.<sup>3b</sup>

**Kinetic Runs.**—All kinetic runs were made in aqueous solutions adjusted to a constant ionic strength of 1.00 *M*. Runs with Py substrate were buffered with either HPO<sub>4</sub><sup>2-</sup>-H<sub>2</sub>PO<sub>4</sub><sup>-</sup> or NH<sub>3</sub>-NH<sub>4</sub><sup>+</sup>, and runs with Im were self-buffered.<sup>3a</sup> The final adjustment to constant ionic strength was made by addition of aqueous NaNO<sub>3</sub>. Some of the runs with Py substrate were followed with a Beckman DU spectrophotometer, equipped with dual thermospacers. Data were taken at 400 m $\mu$ , where the absorbancy of I<sub>3</sub><sup>-</sup> is large and that of I<sub>2</sub> is small.<sup>13</sup> Other kinetic runs with Py and Im substrates were followed by titration with thiosulfate, using the procedure of Berliner.<sup>7</sup> In all runs, the

(1) Taken in part from the M.S. thesis of D. G. Lambert, V.P.I., 1962.

(2) K. W. Doak and A. H. Corwin, *J. Am. Chem. Soc.*, **71**, 159 (1949).

(3) (a) J. H. Ridd, *J. Chem. Soc.*, 1238 (1955); (b) A. Grimison and J. H. Ridd, *ibid.*, 3019 (1959).

(4) C. H. Li, *J. Am. Chem. Soc.*, **66**, 225 (1944).

(5) P. B. D. De La Mare and J. H. Ridd, "Aromatic Substitution: Nitration and Halogenation," Butterworths Scientific Publications, London, 1959, pp. 200-202.

(6) B. S. Painter and F. G. Soper, *J. Chem. Soc.*, 342 (1947).

(7) E. Berliner, *J. Am. Chem. Soc.*, **73**, 4307 (1951).

(8) E. Grovenstein, Jr., and N. S. Aprahamian, *ibid.*, **84**, 212 (1962).

(9) R. Hüttel, O. Schafer, and P. Jochum, *Ann.*, **593**, 200 (1955).

(10) R. D. Brown, *Australian J. Chem.*, **8**, 100 (1955).

(11) H. Reimfinger, A. van Overstraeten, and H. G. Viehe, *Chem. Ber.*, **94**, 1036 (1961).

(12) W. Goodlett, Tennessee Eastman Co., Kingston, Tenn., private communication.

(13) A. D. Autrey and R. E. Connick, *J. Am. Chem. Soc.*, **73**, 1842 (1951).