10% sodium hydroxide solution until the distillate was no longer basic to litmus (200 ml). The distillate was saturated with potassium carbonate and extracted with three 100-ml portions of ether. The combined ether extracts were dried over anhydrous potassium carbonate and the ether was removed by distillation to leave 3.6 g (49% based on the amount of **2a** present in the starting pyrrolidylpropanol mixture) of vpc pure pyrrolizidine (**3**).

B. **Bromide-Hydrobromide Method.**[16]—The solution obtained by adding, with cooling and stirring, 50 ml of cold 48% hydrobromic acid to 7.9 g of the pyrrolidylpropanol mixture **2a** and **2b** was distilled through a Vigreux column until the boiling point reached 99°. The distilland was evaporated to dryness with a rotary evaporator and the resulting dark brown residue was taken up in 50 ml of water which was then added to a solution of 20 g of sodium hydroxide in 150 ml of water. This reaction mixture was steam distilled until the distillate was no longer basic to pH paper. Extraction of the potassium carbonate saturated distillate with three 100-ml portions of ether, followed by drying (potassium carbonate) and distillation of the combined ether extracts through a Vigreux column, afforded 4.7 g of a colorless oil whose vapor phase chromatogram indicated a 7:3 mixture of two components in order of increasing retention time. These components were separated by preparative vpc and identified as pyrrolizidine (**3**) and 1-azabicyclo[3.2.1]octane [**4**, picrate mp 293–295° dec (lit.[17] mp 294–295°), chloroplatinate mp 214–215° (lit.[17] mp 215–215.5°)], respectively.

Attempted Mercuric Acetate Oxidation of Pyrrolizidine (3).—In a 100-ml, three-necked flask fitted with a mechanical stirrer, reflux condenser, and addition funnel was placed 50 g (0.155 mole) of mercuric acetate and 50 ml of 5% aqueous acetic acid. The apparatus was evacuated and refilled with nitrogen several times and warmed until all of the mercuric acetate had dissolved. To the resulting solution was added 2.5 g (0.022 mole) of pyrrolizidine (**3**) and the mixture was heated to reflux with stirring for 48 hr. Upon cooling only a very small amount of mercurous acetate precipitated. The reaction was worked up in the usual manner[6] to afford 1.75 g (70%) of a yellow oil whose infrared spectrum showed no C=C or vinyl hydrogen absorption and which was identical with that of pyrrolizidine (**3**). Vapor phase chromatography similarly indicated no product other than pyrrolizidine.

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The Formation of 2-Aroylpyrroles from Sodiopyrrole and Aromatic Aldehydes

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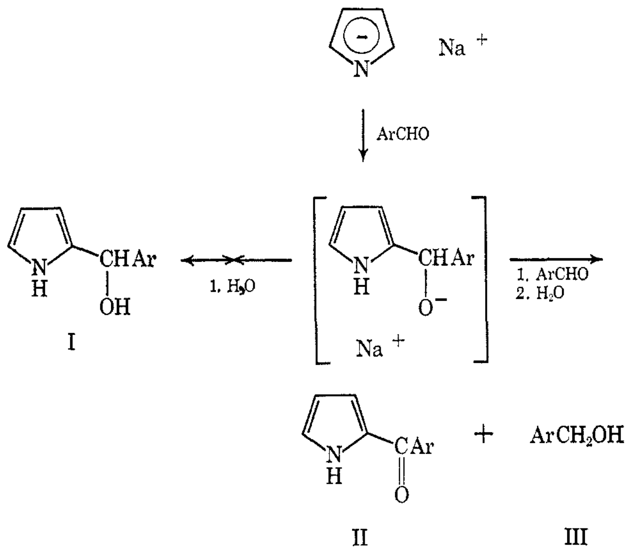
It has been found that the sodium derivative of pyrrole does not give the expected alcohols (I) when allowed to react with aromatic aldehydes, but yields ketones (II). A second product of this reaction is the alcohol (III) corresponding to the reduction product of the aromatic aldehyde employed.

The probable reaction route is related to an alkoxide reduction which frequently takes place during the reaction of Grignard reagents and aldehydes.[1] This type of reaction is a special case of the Meerwein–Ponndorf–Verley reduction[2] or an Oppenauer oxidation[3] in which the intermediate, sodium salt of α-pyrrol-2-ylbenzyl alcohol, is converted into II while a second mole of aromatic aldehyde is reduced to compound III.



IV, Ar = C_6H_5
V, Ar = p-$CH_3OC_6H_4$
VI, Ar = m-ClC_6H_4

The reaction was carried out employing equimolar quantities of the sodium derivative of pyrrole and the aromatic aldehyde which was added to it. No significant change in yield took place when 2 moles of the aromatic aldehyde were added to 1 mole of the sodium derivative of pyrrole.

The ketones IV and V are reported structures having melting points and infrared spectra in agreement with the literature.[4,5] The alcohols were characterized by comparison of their infrared spectra with those of authentic samples (see Table I).

TABLE I

INFRARED SPECTRAL DATA OF AROYLPYRROLES

	$CHCl_3$[a]		$CHCl_3$		KBr	
Compd	νNH, cm^{-1}	νC=O, cm^{-1}	νNH, cm^{-1}	νC=O, cm^{-1}	νNH, cm^{-1}	νC=O, cm^{-1}
IV	3445	1615	3460	1620	3290	1626
V	3450	1620	3460	1605	3300	1610
VI			3460	1622	3300	1621

[a] Literature values from ref 4.

Experimental Section

The General Procedure for the Preparation of 2-Aroylpyrroles.—Pyrrole (0.5 mole, 33.5 g) was added slowly to a stirred refluxing suspension of sodium amide (0.5 mole, 19.5 g) in benzene (500 ml) under a nitrogen atmosphere. Upon completion of the addition of pyrrole, followed by refluxing for 16 hr, the aromatic aldehyde (0.5 mole) was introduced in a dropwise manner to the cooled, stirred suspension. After the aromatic aldehyde addition was completed, the reaction was refluxed for 1 hr and cooled, and water (200 ml) was added cautiously. The layers were separated and the organic layer was washed with water, dried over anhydrous magnesium sulfate, and filtered, and the solvent was removed in a rotary evaporator.

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2-Benzoylpyrrole (IV).—The residue was distilled. The first fraction obtained was benzyl alcohol in a yield of 23.4 g (87%). The second was 2-benzoylpyrrole, bp 105–140° (0.1 mm), yield 23.3 g (54%). Considerable solidification in the column took place during distillation. After recrystallization from benzene, the melting point was 77–78° (lit.[5] mp 78–79°).

Anal. Calcd for $C_{11}H_9NO$ (171.2): C, 77.17; H, 5.30; N, 8.18. Found: C, 77.01; H, 5.48; N, 8.32.

2-(*p*-Methoxybenzoyl)pyrrole (V).—The residue partially solidified on standing and the solid material was removed *via* filtration through a sintered-glass funnel. After recrystallization from ether, a 13.7-g yield (27%) of the ketone (V) having a melting point of 110–112° (lit.[4] mp 110–111°) was obtained. No attempt was made to isolate the expected alcohol, *p*-methoxybenzyl alcohol.

Anal. Calcd for $C_{12}H_{11}NO_2$ (201.2): C, 71.62; H, 5.51; N, 6.96. Found: C, 71.50; H, 5.54; N, 6.97.

2-(*m*-Chlorobenzoyl)pyrrole (VI).—The residue was distilled. The first fraction obtained was *m*-chlorobenzyl alcohol in a yield of 26.2 g (74%). The second fraction, bp 155–165° (0.1 mm), tended to solidify in the column during distillation. The ketone VI (mp 82–86°) was obtained in a 26.9-g yield (53%). After recrystallization from benzene, the melting point was 86–87°.

Anal. Calcd for $C_{11}H_8ClNO$ (205.7): C, 64.25; H, 3.92; N, 6.81. Found: C, 64.44; H, 4.22; N, 6.89.

Alkylation of Pyrrylmagnesium Bromide

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Recent reexaminations of the alkylation of pyrrylmagnesium bromide have shown that a mixture of pyrrole, 2- and 3-alkylpyrroles, and polyalkylpyrroles is produced.[1–3] However, in these studies the recovery of products has been low and the identity of the polyalkylpyrroles remains uncertain. The availability of facile syntheses of all of the isomeric polymethylpyrroles[4] and the development of a method of separating the polyalkylpyrroles by gas chromatography[5] have now made it possible to determine the identity and quantity of the polymethylpyrroles and to account for at least 85% of the material produced in the methylation. In addition it was possible to separate and, by inference, to identify the products from the alkylation with ethyl, *n*-propyl, isopropyl, and *t*-butyl bromide.

Both the slow methylation of pyrrylmagnesium bromide by methyl iodide and the rapid methylation with methyl tosylate were studied. It was observed that methylations with an equivalent amount of methyl iodide, which took about 4 days to consume all of the Grignard, gave a poor recovery of the identifiable products owing to considerable formation of a tar insoluble both in water and ether. Although the amount of tar could be decreased by using an excess of methyl iodide to speed up the reaction, tar formation was completely prevented by shielding the reaction from light.[6] By using a fourfold excess of methyl iodide, the reaction at room temperature was more than 96% complete at the end of 48 hr as shown by titration of any unreacted Grignard. With only the equivalent amount of methyl tosylate, the reaction was complete in less than 30 min. The reactions were quenched with 0.1 *M* phosphoric acid, which, owing to the buffering action, was not acidic enough to cause polymerization of the pyrroles, but did remove the pyrrolenines which gave considerable difficulty in analysis of the product. The product analysis was carried out by gas chromatography on a Tide column at 150° and the integration of the peak areas in conjunction with infrared analysis of the fractions collected. The results are summarized in Table I.

The authentic polymethylpyrroles were prepared and their infrared spectra, gc retention times, and response sensitivity were determined. Although the 2- and 3-methylpyrroles could not be resolved by gas chromatography[5] the ratio of 2- to 3-methylpyrrole could be determined by infrared analysis of the gc fraction. The dimethylpyrrole fraction consisted of two overlapping peaks having the correct retention times for the 2,5- and 2,3-dimethylpyrroles. Their identities were confirmed by comparing the infrared spectrum of the trapped material from each peak with that of the authentic compounds. Since the amount of 2,4- and 3,4-dimethylpyrrole in the dimethylpyrrole fraction was below the limit (*ca.* 5%) of the infrared technique, they must account for less than 1% of the products. The lack of 2,4- and 3,4-dimethylpyrroles is not surprising since it is known that in 3-methylpyrrole it is the 2 rather than the 4 or 5 position which is more activated toward electrophilic attack as long as the entering group is not too bulky.[4,7] The ratio of 2,3- to 2,5-dimethylpyrrole was determined by quantitative infrared analysis of the trapped fraction. The trimethyl- and tetramethylpyrroles were well-resolved peaks and were identified by the infrared spectrum of the trapped material while the quantities were determined from the peak areas.

In addition to the production of 0.9% N-methylpyrrole in the methylation with methyl tosylate as observed by Griffin and Obrycki,[2] a small amount (0.3%) was also detected in the products from the methyl iodide methylation. It can be seen from the ratios of each set of isomers produced that, as expected, the more reactive methyl tosylate is a less discriminating alkylating agent.

It is surprising to observe that in terms of the fate of the methyl groups, methylation by either methyl iodide or tosylate actually produces predominately polymethylation. Only 30.4% of the methylation by methyl iodide and 40.5% of the methylation by methyl tosylate results in monomethylpyrroles. Since polymethylation is due to Grignard exchange between pyrrylmagnesium bromide and the methylated pyrrole,[3,8] it is interesting to note the amount of pyrrole

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