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Base-Catalyzed Reactions. XLIII.[1] Sodium- and Potassium-Catalyzed Side-Chain Alkenylation of γ-Alkylpyridines with Piperylenes

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The sodium- and potassium-catalyzed side-chain alkenylation of γ-picoline and γ-ethylpyridine with *cis*- and *trans*-piperylene was investigated. The alkenylation was carried out at 0 and 40°, and it was initiated by the anions produced from the reaction of 1 g-atom of the alkali metals with the alkylpyridines. The pentenylation occurred exclusively on the alkyl carbon atom α to the pyridine ring. The monopentenylated product from the reaction with *trans*-piperylene consisted mainly of branched-chain isomers and was the result of the addition of the picolyl anion to carbon atom 4 of the piperylene. The monopentenylated product from the reaction with the cis isomer at 0 and at 40° consisted mainly of straight-chain isomers, and the ratio of straight- to branched-chain isomers with potassium was lower than with sodium and was lower when the reactions occurred at the higher temperature. The dipentenylated pyridines were formed almost exclusively from the straight-chain monoadducts. The relative rate constants of monopentenylated isomer formation were calculated. The structures of the alkenylpyridines and of the products of their selective hydrogenations were determined by ir and nmr spectroscopy. The mechanism of the alkenylation reaction is discussed.

It has been previously established in our laboratory that alkylpyridines undergo carbanion-catalyzed side-chain alkylation and alkenylation reactions[2-8] similar to those of alkylbenzenes.[9-14] The reaction proceeds through the addition of 1-pyridylalkyl (picolyl)[15] anion to the double bond of the olefins. The alkenylation with butadiene[5] and isoprene[8] has been reported. The purpose of the present study was to obtain a better understanding of the alkenylation reaction by investigating the selectivity of the addition reaction of γ-alkylpyridines to *cis*- and *trans*-piperylene.

The alkenylation of γ-picoline and γ-ethylpyridine with an equivalent molar amount of either *cis*- or *trans*-piperylene was made at 0° in the presence of catalysts prepared from 1 g-atom of either sodium or potassium. The experiments of γ-picoline with *cis*-piperylene were also made at 40°. The course of the reaction was followed by means of vpc. For quantitative determination of the product, 5 mol % of *n*-butylcyclohexane was added to the alkylpyridines as internal standard for vpc. The separation of the individual compounds was accomplished by preparative gas chromatography. The structures of the pure compounds were determined by nmr and ir, and the structures of the selectively hydrogenated compounds were confirmed by nmr. The structures of the latter were compared with the corresponding synthetically prepared alkylpyridines by the method of Brown and Murphey.[16]

The mechanism of pentanylation of alkylpyridines with piperylene is similar to that proposed for butadiene[5] and isoprene[8] and is presented in Scheme I.

Results and Discussion

Products Formed.—The product obtained from the reaction of piperylenes with γ-picoline is given in Scheme II and that with 4-ethylpyridine in Scheme III. The relative rates of formation of the individual monoadduct isomers and the total yield of the diadducts are given in Tables I, II, and III.

Products of chain lengthening similar to those observed in the alkenylation of toluene[12] were not observed and neither were found products containing terminal double bonds or those having a double bond in conjuga-

(1) (a) For paper XLII, see H. Pines, S. V. Kannan, and J. Simonik, *J. Org. Chem.*, **36**, 2311 (1971). (b) Paper XIII of the series Alkylation of Heteroaromatics. For paper XII, see H. Pines, S. V. Kannan, and W. M. Stalick, *ibid.*, **36**, 2308 (1971).

(2) For general review see H. Pines and L. Schaap, *Advan. Catal.*, **12**, 117 (1960).

(3) H. Pines and B. Notari, *J. Amer. Chem. Soc.*, **82**, 2209 (1960).

(4) B. Notari and H. Pines, *ibid.*, **82**, 2945 (1960).

(5) H. Pines and J. Oszczapowicz, *J. Org. Chem.*, **32**, 3183 (1967).

(6) H. Pines and N. E. Sartoris, *ibid.*, **34**, 2113 (1969).

(7) N. E. Sartoris and H. Pines, *ibid.*, **34**, 2119 (1969).

(8) (a) W. M. Stalick and H. Pines, *ibid.*, **35**, 415 (1970); (b) *ibid.*, **35**, 422 (1970).

(9) S. V. Kannan and H. Pines, *ibid.*, **36**, 2304 (1971).

(10) H. Pines and J. Shabtai, *ibid.*, **26**, 4220 (1961).

(11) J. Shabtai and H. Pines, *ibid.*, **26**, 4225 (1961).

(12) H. Pines and N. C. Sih, *ibid.*, **30**, 280 (1965).

(13) B. Stipanović and H. Pines, *ibid.*, **34**, 2106 (1969).

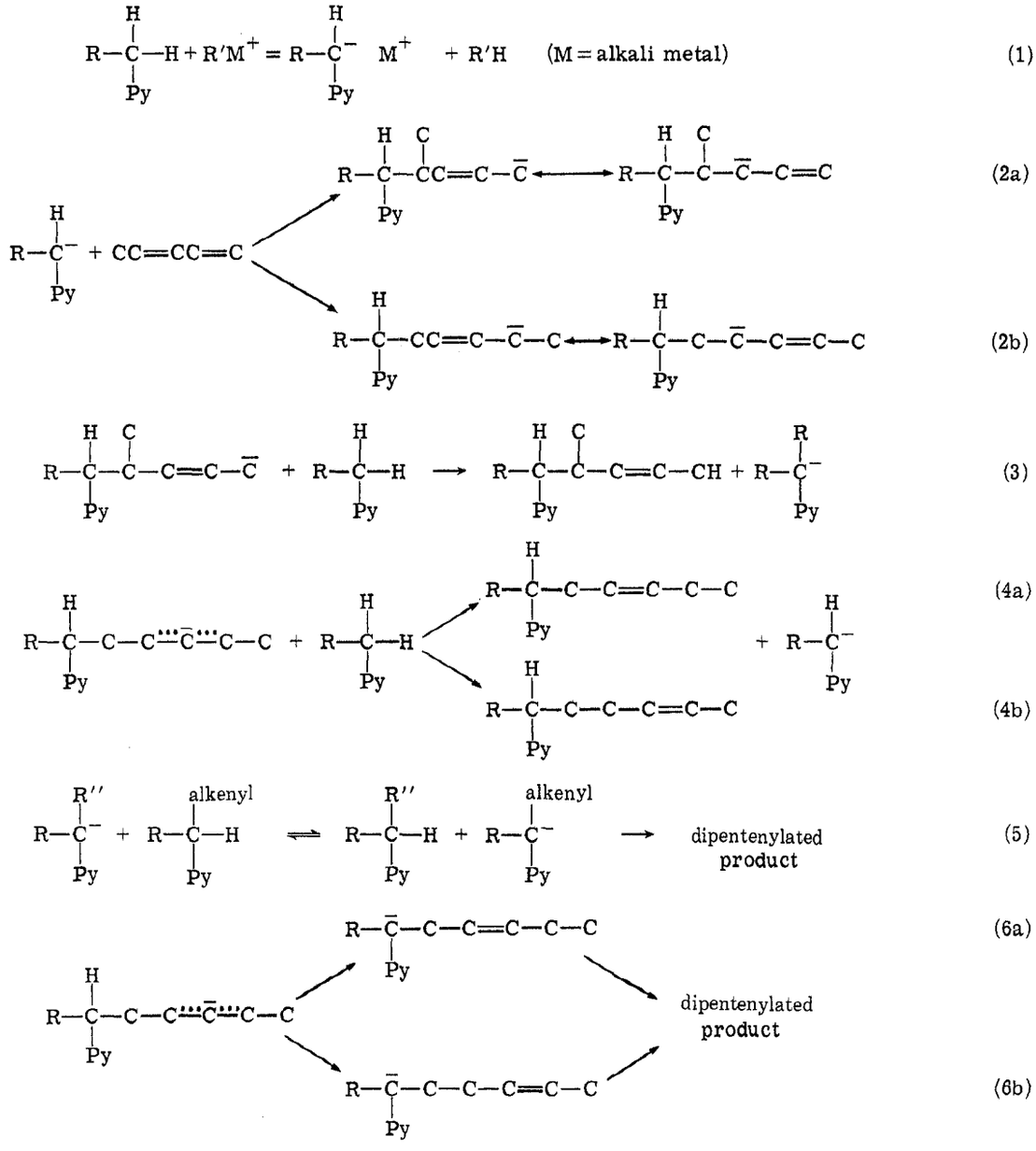
(14) B. Stipanović and H. Pines, *Chem. Commun.*, 1362 (1969).

(15) Picolyl anion throughout the paper is defined as an anion on the α-carbon atom of the alkyl group of the pyridine ring.

(16) H. C. Brown and W. A. Murphey, *J. Amer. Chem. Soc.*, **73**, 3308 (1951).

SCHEME I

MECHANISTIC PRESENTATION OF PENTENYLATION OF ALKYLPYRIDINES



tion with the pyridine ring, and this is in agreement with previous results from the alkenylation of alkylpyridines.[5,8] The isomeric piperylenes did not undergo reversible isomerization during the reaction.

The skeletal structures of the alkenylated γ-picoline obtained at 0° in the presence of either sodium or potassium depended primarily on the piperylene isomer used in the reaction. With the *cis*-piperylene the monoalkenylated product consisted of over 85% of straight-chain compounds, while with the trans isomer about 80% of branched-chain monoaddition products were formed (Table I, expt 1–4). Potassium was slightly less selective than sodium and this was especially true when the reaction was carried out at 40° instead of 0° (Table I, expt 5 and 6). At the higher temperature the rate of reaction was about 50% greater. The selectivity of addition of 4-ethylpyridine to the isomeric piperylenes was of the same type but of higher magnitude than that of picoline.

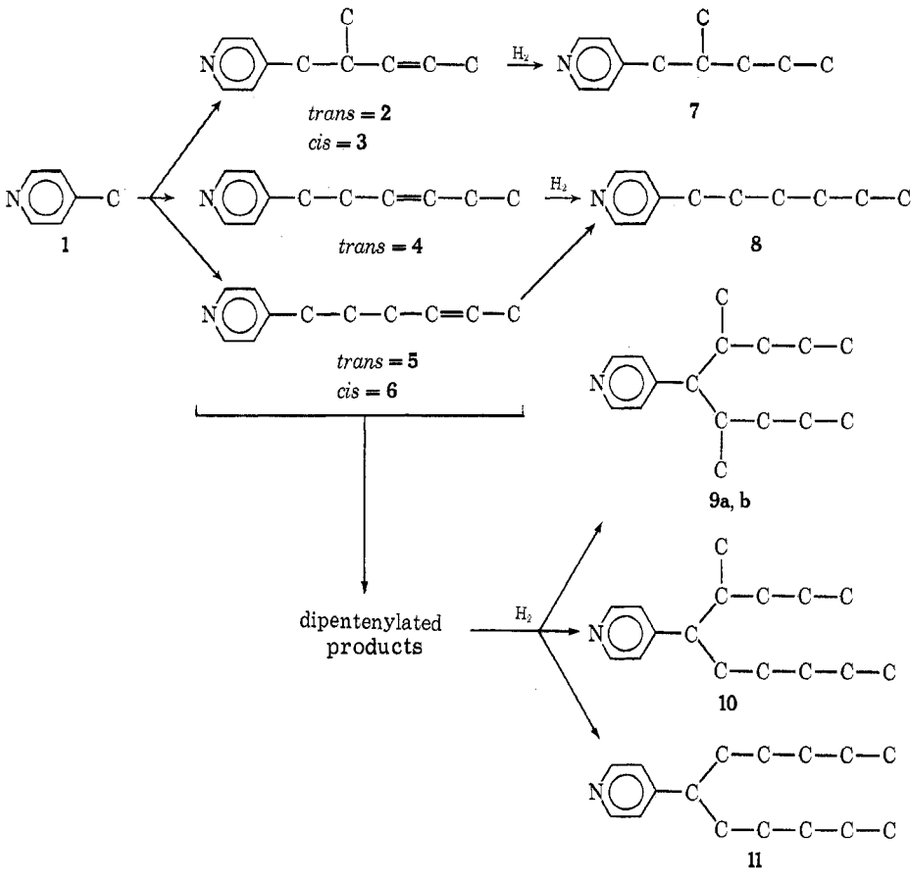
The pentenylation of γ-picoline with *trans*-piperylene produced a mixture of *trans*- and *cis*-4-methyl-5-(4-pyridyl)-2-pentene (**2** and **3**), *trans*-6-(4-pyridyl)-3-hexene (**4**), *trans*-6-(4-pyridyl)-2-hexene (**5**), and several dipentylated compounds. The latter, after selective hydrogenation, formed 4,6-dimethyl-5-(4-pyridyl)-nonane (**9**), 4-methyl-5-(4-pyridyl)decane (**10**), and 5-(4-pyridyl)undecane, the main product being **10**.

Pentenylation of γ-picoline with *cis*-piperylene gave also isomers **2**, **3**, and **4**, but, instead of **5**, *cis*-6-(4-pyridyl)-2-hexene (**6**) was formed. The dipentylated product after selective hydrogenation yielded almost exclusively **11**.

Pentenylation of 4-ethylpyridine with *trans*-piperylene formed four monoadducts: *trans*- and *cis*-4-methyl-5-(4-pyridyl)-2-hexene (**13** and **14**), *trans*-6-(4-pyridyl)-3-heptene (**15**), and *cis*-6-(4-pyridyl)-2-heptene (**16**) (Scheme III). With *cis*-piperylene only three monoadducts were obtained, **13**, **15**, and **16**.

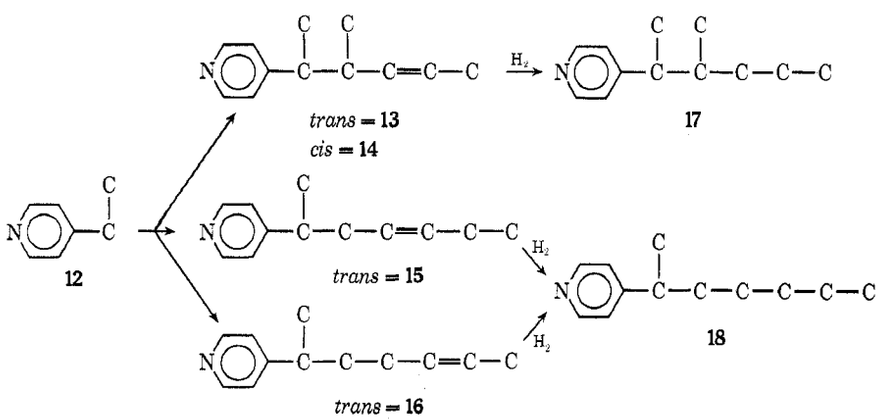
SCHEME II

PRODUCTS FORMED FROM REACTION OF γ-PICOLINE WITH PIPERYLENES



SCHEME III

PRODUCTS FORMED FROM REACTION OF 4-ETHYLPYRIDINE WITH PIPERYLENES



Isomer **14** was not detected even when 40% of the 4-ethylpyridine reacted. The yield of diadducts, with both *cis*- and *trans*-piperylene, was very low, less than 1%.

Distribution of Products.—The ratio of straight-chain to branched-chain alkenylpyridines depends greatly on the piperylenes and alkylpyridines used in the reactions, and to a smaller extent on the catalysts and temperatures. This ratio indicates the relative susceptibility of the isomeric piperylenes to undergo an attack on the 1- or 4-carbon atom by the picolyl anion. This ratio was constant during pentenylation of 4-ethylpyridine and was changing in the case of γ-picoline.

The rate of formation of isomeric monopentenylated alkylpyridines depends on several factors, such as the catalyst used in the reaction, configuration of piperylene, the structure of alkylpyridine employed, and the temperature of the reaction.

The monopentenylated pyridines can be produced either by reaction 2a and 3 or by 2b and 4 (Scheme I). The dipentenylated pyridines can be formed as a result of a parallel reaction 2b and 6, or a consecutive reaction 2b, 4, and 5. Since the rate of the consecutive

TABLE I

PENTENYLATION OF γ-PICOLINE WITH *cis*- AND *trans*-PIPERYLENE[a]

Expt no.	Piperylene, catalyst, temp, °C	Sample no.	Time, hr	Conversion, %[b]	Yield of isomers, %[b,c] — Monopentenylated — Branched chain, 2 + 3	Straight chain, 4	Straight chain, 5	Straight chain, 6	Dipentenylated, total	Isomers distribution: 4 + 5 + 6 / 2 + 3	Isomers distribution: 5 or 6 / 4	Di / mono
		1	1.0	1.49	0.88	0.14	0.24	0	0.228	0.43	1.79	0.18
		2	2.0	3.92	2.62	0.20	0.61	0	0.490	0.31	2.97	0.14
	trans-,	3	3.5	8.18	5.40	0.41	1.23	0	1.142	0.30	2.97	0.16
1	Na,	4	5.0	9.19	6.12	0.43	1.37	0	1.271	0.29	3.23	0.16
	0	5	7.0	13.23	8.63	0.57	1.95	0	2.09	0.29	3.44	0.18
		6	10.0	19.85	13.14	0.78	2.72	0	3.21[d]	0.27	3.49	0.19
		1	1.0	0.84	0.52	0.10	0.14	0	0.084	0.45	1.38	0.11
		2	2.0	1.93	1.29	0.20	0.24	0	0.202	0.34	1.20	0.12
	trans-,	3	3.5	2.65	1.74	0.24	0.41	0	0.259	0.37	1.76	0.11
2	K,	4	5.0	3.72	2.49	0.28	0.61	0	0.340	0.36	2.16	0.10
	0	5	7.0	5.51	3.62	0.36	0.79	0	0.730	0.32	2.18	0.15
		6	10.0	7.12	4.24	0.42	1.02	0	1.44[d]	0.34	2.43	0.25
		1	1.0	2.66	0.16	0.66	0	0.98	0.86	10.4	1.47	0.48
		2	2.0	5.08	0.30	0.96	0	1.60	2.22	8.47	1.67	0.78
	cis-,	3	3.5	8.10	0.50	1.22	0	2.48	3.90	7.44	2.03	0.94
3	Na,	4	5.0	10.16	0.60	1.28	0	2.95	5.33	7.04	2.30	1.10
	0	5	7.0	12.67	0.73	1.50	0	3.48	6.96	6.82	2.33	1.22
		6	10.0	15.88	0.82	1.62	0	4.03	9.41[e]	6.87	2.48	1.46
		1	1.0	3.40	0.295	0.900	0	1.36	0.845	7.66	1.51	0.33
		2	2.0	5.65	0.498	1.36	0	2.12	1.67	6.99	1.56	0.42
	cis-,	3	3.5	8.12	0.653	1.64	0	2.85	2.98	6.87	1.73	0.58
4	K,	4	5.0	9.63	0.837	1.88	0	3.24	3.67	6.12	1.72	0.62
	0	5	7.0	10.25	0.862	1.92	0	3.43	4.04	7.20	1.78	0.65
		6	10.0	11.32	0.904	2.07	0	3.67	4.68[e]	6.35	1.77	0.70
		1	1.0	4.28	0.343	1.28	0	1.86	0.80	9.13	1.45	0.23
		2	2.0	8.17	0.591	2.08	0	3.28	2.22	9.07	1.58	0.37
	cis-,	3	3.5	13.32	0.919	2.86	0	4.93	4.51	8.47	1.76	0.51
5	Na,	4	5.0	17.20	1.11	3.32	0	5.61	7.16	8.05	1.69	0.71
	40	5	7.0	21.14	1.33	3.62	0	6.26	9.93	7.43	1.73	0.89
		6	10.0	23.99	1.44	3.85	0	6.60	12.1[e]	7.26	1.72	1.02
		1	1.0	5.28	0.789	1.38	0	2.04	1.07	4.34	1.47	0.25
		2	2.0	9.07	1.32	1.98	0	3.33	2.44	4.02	1.68	0.37
	cis-,	3	3.5	12.04	1.79	2.38	0	4.23	3.64	3.69	1.77	0.43
6	K,	4	5.0	13.42	1.94	2.56	0	4.52	4.40	3.64	1.77	0.49
	40	5	7.0	14.59	2.13	2.61	0	4.75	5.10	3.46	1.82	0.54
		6	10.0	14.86	2.14	2.64	0	4.81	5.27[e]	3.48	1.82	0.54

[a] The following mole equivalents of active reagents were used: picoline, 1.0; piperylene, 1.0; alkali metal, 0.01 g-atom. For details see Experimental Section, General Procedure. [b] Based on γ-picoline used in the reaction. [c] The boldface numbers refer to compounds given in the text. [d] Selective hydrogenation gave mainly **10**. [e] Selective hydrogenation gave **11** with a small amount of **10**.

reaction can be ignored at very low conversions, the consumption of alkylpyridines in an overall reaction can be expressed by

$$-\frac{d[PyCR]}{dt} = \frac{dx}{dt} = k_{\Sigma}q[p - x][a - x] \qquad (I)$$

where [PyCR] = actual concentration of starting alkylpyridine, p = initial concentration of starting alkylpyridine, a = initial concentration of piperylene, q = concentration of the catalyst, x = total concentration of pentylated pyridines, and k_{Σ} = rate constant for overall reaction.

The rates of formation of the individual pentenylated compounds can be expressed by a similar equation

$$\frac{dx_n}{dt} = k_n q[p - x][a - x] \qquad (II)$$

where x_n = concentration of pentenylated product n and k_n = rate constant of formation of compound n.

Dividing eq I by eq II and integrating between the limits of concentration from 0 to x and x_n, respectively, eq III is obtained.

$$x_n/x = k_n/k_{\Sigma} \qquad (IIIa)$$

$$k_n = [x_n/x]k_{\Sigma} \qquad (IIIb)$$

The relative rate constants $k_n' = k_n/k_{\Sigma}$ for the formation of the various pentenylated products derived from eq III are given in Table III.

Equation III shows that mole per cent of isomer n formed can be plotted as a function of the amount of alkylpyridine reacted and that the plot should give a straight line. This would be true only if product n is formed as a result of the parallel reaction only and it it does not undergo any further reaction.

Figure 1 shows that branched-chain monopentenylated pyridines do not take part in the formation of dipentenylated products, inasmuch as the plot follows a straight line. Compound **4**, containing a double bond at the γ–δ position with respect to the pyridine ring, undergoes further pentenylation (reaction 5,

TABLE II

PENTENYLATION OF 4-ETHYLPYRIDINE WITH *cis*- AND *trans*-PIPERYLENE[a]

Expt no.	Piperylene, catalyst, temp, °C	Sample no.	Time, hr	Conversion, %[b]	Yield of isomers, %[b,c] Branched chain 13	Branched chain 14	Straight chain 15	Straight chain 16	Isomer distribution (15 + 16)/(13 + 14)	Isomer distribution 16/15
		1	1.0	2.75	0.83	0.89	0.37	0.67	0.60	1.80
		2	2.0	6.18	1.78	1.51	0.97	1.92	0.88	1.97
	trans-,	3	3.5	11.38	3.54	2.89	1.58	3.37	0.77	2.12
1	Na,	4	5.0	14.64	4.65	4.03	1.92	4.04	0.69	2.11
	0	5	7.0	22.95	7.12	5.47	3.22	7.14	0.82	2.22
		6	10.0	32.48	11.8	6.32	4.46	9.90	0.79	2.22
		1	1.0	1.89	0.56	0.40	0.40	0.54	0.97	1.34
		2	2.0	4.78	1.38	1.15	0.88	1.36	0.89	1.55
	trans-,	3	3.5	8.76	2.54	2.12	1.67	2.43	0.88	1.46
2	K,	4	5.0	11.52	3.41	2.73	2.16	3.22	0.89	1.51
	0	5	7.0	15.64	4.55	3.67	2.96	4.46	0.90	1.51
		6	10.0	19.44	6.09	3.79	3.69	5.87	0.97	1.59
		1	1.0	3.23	0.09	0	1.45	1.68		1.15
		2	2.0	8.02	0.255	0	3.59	4.17	30.4	1.16
	cis-,	3	3.5	11.78	0.359	0	5.19	6.23	31.8	1.20
3	Na,	4	5.0	21.92	0.612	0	9.37	11.94	34.8	1.27
	0	5	7.0	27.88	0.883	0	12.2	14.8	30.6	1.21
		6	10.0	40.9	1.30	0	17.9	21.7	30.5	1.21
		1	1.0	4.81	0.22	0	1.84	2.75	20.9	
		2	2.0	11.4	0.48	0	5.61	5.39	24.4	0.96
	cis-,	3	3.5	22.4	1.01	0	10.6	10.8	21.2	1.01
4	K,	4	5.0	28.9	1.18	0	13.8	13.9	24.8	1.01
	0	5	7.0	34.9	1.54	0	16.1	17.3	21.6	1.08
		6	10.0	37.4	1.72	0	17.6	18.1	20.6	1.03

[a] See Table I, footnote *a*. [b] Based on 4-ethylpyridine used in the reaction. [c] The boldface numbers refer to compounds given in the text.

TABLE III

RELATIVE RATE CONSTANTS OF PENTENYLATION OF γ-PICOLINE[a]

Expt no.	1	2	3	4	5	6
Piperylene	*trans*-		*cis*-			
Catalyst	Na	K	Na	K	Na	K
Temp, °C	0	0	0	0	40	40
Picoline consumption, k_Σ[a]	1.6	1.0	2.0	2.8	3.8	5.0
Pentenylated product						
$k_2 + k_3/k_\Sigma$	0.65	0.65	0.05	0.08	0.08	0.14
k_4/k_Σ	0.04	0.11	0.23	0.30	0.29	0.30
k_5/k_Σ	0.14	0.14				
k_6/k_Σ			0.45	0.38	0.44	0.38
k_{di}/k_Σ	0.15	0.15	0.26	0.22	0.18	0.17
$\frac{k_4 + k_5 + k_6}{k_2 + k_3}$ = S/B[b]	0.28	0.38	13.5	8.5	9.1	4.8
k_{di}/k_{mono}[c]	0.18	0.18	0.36	0.29	0.22	0.21

[a] Based on data given in Table I. [b] S/B = straight chain/branched chain monopentenylated product. [c] Di-/monopentenylated product.

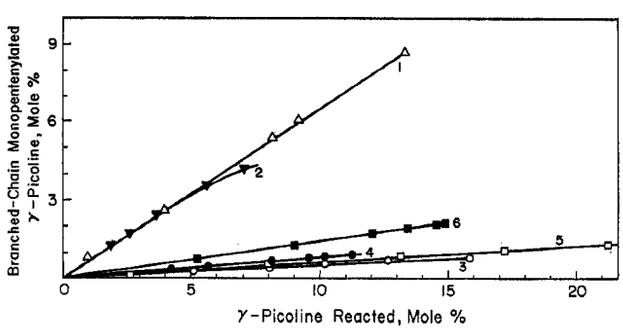
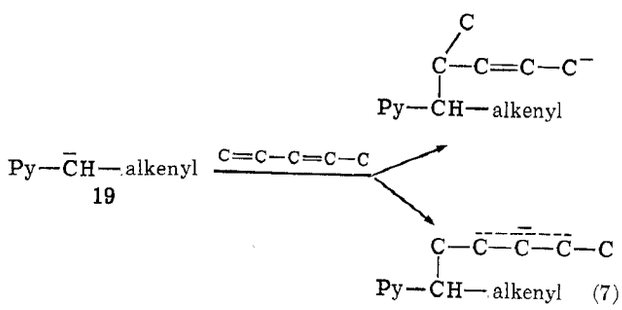


Figure 1.—Mole per cent of branched chain of monopentenylated products obtained from γ-picoline as a function of γ-picoline reacted. (The numbers refer to experiments listed in Table I.)

Scheme I) at a higher rate than those of the other straight-chain isomers **5** and **6**. For that reason the ratios of **5** to **4** and of **6** to **4** change during the reaction (Table I). The difference in the rate of further pentenylation of monopentenylpyridines can be explained by increased acidity of picolyl protons in compounds having double bonds at the γ–δ positions, as was reported previously.[2,6,8]

Dipentenylated products are formed as a result of the reaction of anion **19** with piperylene (eq 7).

The anion **19** can be generated in two ways. (1) It can be formed as a result of intermolecular transprotonation (reaction 5, Scheme I), and the rate of its formation would depend on the concentration of the monopentenylated isomers taking part in the consecutive reaction. In this case the ratio of dipentenylated to the monopentenylated isomers, di/mono, would be equal to zero at zero conversion and would increase with time, giving a plot with an upward curve. (2) The anion **19** may also be formed as a result of intramolecular transprotonation (reaction 6), and the rate of its formation would depend on the probability of such a process. The dipentenylated products would



thus be formed in a parallel reaction, and the kinetics would be described by eq II and IIIa. The ratio $k_{di}/k_{mono} = x_{di}/x_{mono}$ would be equal to the ratio of the number of those undergoing intermolecular protonation, N_{intra}, to the number of those undergoing intermolecular protonation, N_{bi}. Actually the formation of anion **19** occurs by both ways simultaneously, and the ratio of intra- to intermolecular protonation was estimated by the extrapolation of the ratio of x_{di}/x_{mono} to zero conversion, or from the ratio

$$\frac{N_{intra}}{N_{bi}} = \frac{k_{di}}{k_2 + k_3 + k_4 + k_5 + k_6} = \frac{K_{di}}{k_{mono}}$$

The calculated data (Table III) show that at 0° considerable intramolecular transprotonation occurs. The ratio of rate constants of formation straight-chain to branched-chain pentenylpyridines is a measure of the susceptibility of the piperylene isomer to an attack by a picolyl anion in position 1 over position 4 (Table III).

The relative rate constant of overall reaction, k_Σ, was obtained by taking the slowest reaction as a unit. The rates were calculated from the initial slope of a total yield *vs.* time curve, based on the data given in Tables I and II. Since the same amount of gram-atoms of alkali metal was used in each experiment, it was assumed that the same concentration of catalyst was also present. In the pentenylation of γ-ethylpyridine the ratio of the isomeric products formed was constant within the experimental error (Table II). The relative rate constant of the isomers produced is listed in Table IV. The very low formation of di-

TABLE IV

RELATIVE RATE CONSTANTS OF PENTENYLATION OF γ-ETHYLPYRIDINE[a]

Expt no.	1	2	3	4
Piperylene	*trans*		*cis*	
Catalyst	Na	K	Na	K
Temp, °C	0	0	0	0
Ethylpyridine consumption, $k^1\Sigma$[b]	2.5	1.7	3.2	4.5
Pentenylated product				
k_{13}/k_Σ	0.30	0.30	0.03	0.04
k_{14}/k_Σ	0.26	0.23		
k_{15}/k_Σ	0.13	0.20	0.43	0.47
k_{16}/k_Σ	0.29	0.27	0.52	0.48
$\frac{k_{15} + k_{16}}{k_{13} + k_{14}}$	0.75	0.89	0.32	0.21

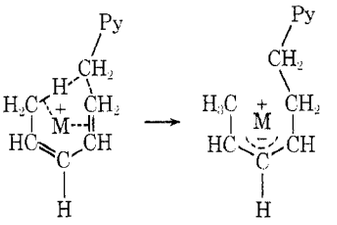
[a] Based on data given in Table II. [b] Relative to picoline consumption, Tables I and III.

pentenylated compounds in the case of ethylpyridine is most likely due to steric hindrance caused by the methyl and alkenyl groups situated at the picolyl carbon atom, and it is similar to the observation made in the case of 4-*sec*-butylpyridine.[8a]

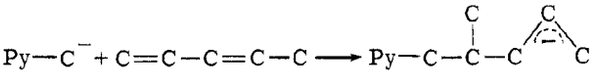
The relative rate of pentenylation of ethylpyridine with piperylene is about 1.5 times that of γ-picoline, which is in accordance with the results obtained previously with isoprene.[8]

Reactivity of *cis*- and *trans*-Piperylene.—γ-Picoline was treated with technical grade piperylene containing a mixture of cis and trans isomer. From the rate of the disappearance of the two isomers it was found that the cis isomer reacts about nine times faster than the trans isomer. The greater reactivity of *cis*-piperylene could by attributed to its polarization caused by the approaching picolyl anion. It is known that the protons of the methyl group in piperylene could be readily replaced by sodium during transmetalation with alkylsodium.[17] In the presence, however, of a relatively strong acid, such as γ-picoline, metalation of piperylene does not occur, as indicated by the absence of cis–trans isomerization of the dienes during the alkenylation reaction. It is, however, very plausible that the methyl group of piperylene can form strong hydrogen bonding with a picolyl anion and thus cause a change in polarization of the cis and trans diene. In the cis isomer only there is a possibility for an approach of the C-1 atom by a free rotation around the C-2–C-3 bond to the hydrogen-bonded picolyl anion. The reaction between the anion and the diene could then occur while the polarization of the molecule is still maintained, and as a result of this interaction an addition of a picolyl anion to the terminal double bond may occur to give a straight-chain adduct.

The transition state of the reaction can be presented as follows.



The stabilization of a not fully developed anion in position 5 relative to the double bond is suggested by previous alkenylation studies.[5,7] Since *trans*-piperylene cannot have such a configuration, the addition occurs in the carbon 4, because the resulting primary–secondary anion is more stable than the secondary–secondary as in the case of the addition of picolyl anion to the terminal double bond.



The temperature increase diminishes the probability of a required conformation, and thus the ratio of straight-chain to branched-chain isomers is lower (expt 5 and 6).

Structure Determination.—The product from the alkenylation of the alkylpyridines with piperylene was submitted to a distillation and frequent fraction were taken. The various fractions were then separated into pure compound by vpc. A portion of the fractions containing mostly one isomer was selectively hydrogenated to the corresponding alkylpyridines. The hydrogenation was made at atmospheric pressure using palladium as catalyst, and from the amount of hydrogen absorbed it was possible to determine the number of double bonds per molecule. The nmr and ir spectra of the individual alkyl- and alkenylpyridines are given in Tables III and IV.

The various groups of protons were determined from the position, intensity, and multiplicity of the resonance bands. Characteristic protons are listed in Table V. The total number of aliphatic protons and the number

(17) A. A. Morton, F. D. Marsh, R. D. Coombs, A. L. Lyons, S. E. Penner, H. E. Ramsden, V. B. Baker, E. L. Little, and R. L. Letsinger, *J. Amer. Chem. Soc.*, **72**, 3785 (1950).

TABLE V

CHARACTERIZATION AND NMR SPECTRA OF γ-ALKYL- AND γ-ALKENYLPYRIDINES DERIVED FROM PENTENYLATION OF γ-PICOLINE

			Spectra of pyridines[a-c] Chemical shift, δ, ppm						
Compd	Bp, °C (mm)	$n^{21}D$	CH_3CCPy	CH_3CCC	C_n CH_3CPy	$CH_3C{=}C$	$CH_2C{=}C$	Picolyl protons	Olefinic protons
2		1.5068	0.96 d			1.59 d		2.51	5.37
	78 (3.5)								
3			0.96 d			1.41 d		2.51	5.37
4	90 (2)	1.5081		0.94 t			1.90[d] ~2.3[e]	2.69 t	5.47
5	101 (2)	1.5085				1.67 d	2.08	2.60	5.47
6		1.5108				1.60 d	~2.1	2.62 t	5.46
7	90 (4)	1.4907	0.84 d	0.89 t				2.49	
8	79 (1, 5)	1.4890		0.90 t				2.59 t	
9a		1.489	0.75 d	0.89 t				2.16	
9b		1.4896	0.74 d 0.82 d	0.93 t				2.34	
10		1.487	0.71 d 0.81 d	0.91 t				2.42	
11		1.4865		0.85 t				2.48	
13		1.5067	0.94 d		1.20 d 1.24 d	1.59 d		~2.6	5.37
	119 (9.5)								
14		1.5078	0.95 d		1.26 d	1.49 d		~2.6	5.35
15		1.5041		0.93 t	1.25 d		~1.90[d] ~2.3[e]	2.74	5.42
	126 (10)								
16		1.509			1.26 d	1.61 d	2.05	2.73	5.43
17		1.4196	0.74 d 0.84 d	0.90 t	1.19 d 1.24 d			2.58	
18		1.4867		0.87 t	1.24 d			2.67	

[a] In the nmr spectra of all the compounds listed the bands of the two β pyridine protons at δ 7.05–7.21 ppm and the two α-pyridine protons at δ 8.50–8.60 ppm were present. [b] d = doublet; t = triplet. [c] Tetramethylsilicon (TMS) was used as a reference. [d] CH_2 between CH_3 and C=C. [e] CH_2 β to pyridine ring.

of protons causing multiplets were determined from an integration curve. The α- and β-pyridine protons were taken as internal standards for integration. In all the compounds the absorption bands of the two α-pyridine protons at δ 8.50–8.60 ppm and the two β-pyridine protons at δ 7.05–7.21 ppm were present, indicating that the substitution occurred only at the γ-pyridine side chain. The most significant resonance bands were those of CH_3 groups and bands of substituents at the C=C group. A doublet of the CH_3 group at the C atom β to the pyridine ring, CH_3CCPy, at δ 0.74–0.96 ppm indicated the branched-chain isomer. In the cases of dipentenylated products of picoline, **9b** and **10**, and monopentenylated ethylpyridine, **17**, two doublets were due to erythro and threo isomers.

The position of the C=C bond was indicated by the number of $CH_2C{=}C$ protons absorbing at δ 1.98–2.08 ppm and confirmed by the presence or absence of the $CH_3C{=}C$ band at δ 1.41–1.67 ppm. The protons at the picoline carbon atom connected to the pyridine ring absorbed in the range δ 2.16–2.74 ppm; from the number of protons the substitution at this atom was determined. The $-CH_2-$ groups linked with a saturated carbon atom gave broad bands with the maximum located in the region δ 1.12–1.42 ppm.

Cis and trans isomers of the alkenylpyridines were differentiated by the presence and absence of the specific bands in the infrared spectra before and after selective hydrogenation. The bands were at 970–960 cm^{-1} for trans and 1310–1295 and about 690 cm^{-1} for cis. The differentiation between the cis and trans isomers containing methyl group adjacent to the double bond, $CH_3C{=}C-$, was confirmed by the nmr spectra. The resonance band of the CH_3 group in the cis isomer shifted about 0.10–0.18 ppm upfield with reference to the corresponding band of the trans isomer.[18]

Experimental Section

Reagents.—γ-Picoline and 4-ethylpyridine were purchased from Reilly Tar Co. The material was dried over barium oxide and distilled in a nitrogen atmosphere on a Podbielniak Heligrid column, 1.5 m long. The alkylpyridines used in the reaction were over 99.5% pure as adjudged by gas chromatography. *n*-Butylcyclohexane used as an internal standard was obtained by catalytic hydrogenation of *n*-butylbenzene.[5]

cis-Piperylene was isolated from commercial piperylene by the method of Frank, *et al.*,[19] and the piperylene prepared in this manner contained 66.7% *cis*-piperylene and 33.3% cyclopentene and was free from *trans*-piperylene. *trans*-Piperylene, which was purchased from Chemical Samples Co., Columbus, Ohio, contained 94.6% of trans and 1.2% of cis isomer; the remaining 4.2% consisted of cyclopentene, which was inert in this reaction.

General Procedure.—The preparation of the catalysts and the alkenylation reactions were performed according to the procedure described previously.[5]

For preparative purposes, in order to obtain larger amounts of isomers for the establishment of structures, 1.5 mol of alkylpyridines was pentenylated with 1.7 mol of technical grade piperylene and in the presence of 0.05 g-atom of sodium. After the piperylene had reacted, the catalyst was decomposed with methanol until the solution became colorless or pale yellow. The product was then distilled on a Podbielniak Heligrid column, and

(18) L. M. Jackman and R. H. Wiley, *J. Chem. Soc.*, 2881 (1960).

(19) R. L. Frank, R. D. Emmick, and R. S. Johnson, *J. Amer. Chem. Soc.*, **69**, 2313 (1947).

TABLE VI
DESCRIPTION OF THE VAPOR PHASE CHROMATOGRAPHIC COLUMNS

Column	Packing: Liquid phase	Wt %	Solid support	Mesh size	Column: Length, m	O.d., in.
A	Gum rubber phenyl Methyl GE-SE-552	15	GAS-Pack WAB	60–80	1.5	1/4
B	Versamid 900	10	GAS-Pack WAB	60–80	1.5	1/4
C	Dimethyl sulfolane	33	Firebrick	100–120	3.0	1/4
D	Reoplex 400	15	GAS-Pack WAB	60–80	2.3	3/8
E	Versamid 900	15	GAS-Pack WAB	60–80	2.3	3/8

pure isomers were separated by vpc and analyzed spectroscopically.

Analyses.—The infrared spectra of the pyridines purified by gas chromatography were taken with a Baird infrared spectrophotometer, Model 4-55. Samples of 8-10 μl were placed between two sodium chloride plates using air as a reference.

Nmr spectra were obtained on a Varian A-60 spectrometer at room temperature. Samples varying from 20 to 50 μl in carbon tetrachloride, total volume 400 μl, with an addition of 1–2 drops of tetramethylsilicon (TMS) as reference were used (Table V).

Refractive indices were measured on a Zeiss Opton refractometer with a thermostat at 20 ± 0.1°. All samples used for analysis were of purity higher than 95%.

Analyses and separations were performed with an F & M Model 720 dual-column gas chromatograph with a thermal conductivity detector, using helium as a carrier gas. The columns used are listed in Table VI.

The yields of alkenylated pyridines were determined by calculating the peak areas in relation to the internal standard *n*-butylcyclohexane added in known amount before alkenylation. The peak areas were determined from their heights and standard deviations[20] using the Bartlett and Smith method[21] in case of overlapped peaks.

The composition, purity, and consumption of piperylene was analyzed on column C at a column temperature of 30° and an injection port temperature of 70°, helium flow 100 ml/min, inlet pressure 35 psi; 20-μl samples were injected.

The composition of the product obtained from the reaction of γ-picoline with either *cis*- or *trans*-piperylene was analyzed on column A at 170° with a helium flow of 100 ml/min and an inlet pressure of 35 psi. The composition of the reaction products of 4-ethylpyridine was analyzed on column B at 160° with the same helium flow and inlet pressure; 40-μl samples were injected.

For preparative separation and purification of the various alkenylpyridines, the following conditions were used (compound, column, temperature, helium flow in ml/min): **2**, **3**, **4**, **7**, and **8**, D, 160°, 100; **5** and **6**, D, 140°, 125; **9a**, **9b**, **10**, and **11**, E, 190–200°, 100; **13**, **14**, **15**, **16**, **17**, and **18**, E, 170°, 100. The product obtained from each separation was analyzed again on vpc and when necessary the compound was repurified. The relative retention times of the alkyl- and alkenylpyridines are described separately.[22]

Registry No.—**1**, 108-89-4; **2**, 34993-35-6; **3**, 34993-36-7; **4**, 34993-37-8; **5**, 34993-38-9; **6**, 34993-39-0; **7**, 34993-40-3; **8**, 27876-24-0; **9a**, 34993-42-5; **10**, 34993-43-6; **11**, 34993-44-7; **12**, 536-75-4; **13**, 34993-45-8; **14**, 34993-46-9; **15**, 34993-47-0; **16**, 34993-48-1; **17**, 34993-49-2; **18**, 34993-50-5; *cis*-piperylene, 1574-41-0; *trans*-piperylene, 2004-70-8.

(20) O. E. Schupp, "Gas Chromatography," Interscience, New York, N. Y., 1968.
(21) K. C. Bartlett and D. M. Smith, *Can. J. Chem.*, **38**, 2057 (1960).
(22) J. Oszczapowicz, J. Golab, and H. Pines, *J. Chromatogr.*, **64**, 1 (1972).

Alkylation of Disodioacetylacetone with Halo Ketals

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The reaction of bromo and chloro ketals (II) with disodioacetylacetone (I) were investigated. For II, n = 1; X = Br or Cl; R = CH_3—no reaction occurred. For II, n = 2; X = Br; R = CH_3—alkylation occurred in low yield. For II, n = 3, 4, or 5; X = Br or Cl; R = CH_3 or CH_3CH_2—alkylation occurred in fair to good yields to form the terminal alkylation products. These ketal β-diketones were hydrolized to the corresponding triketones. Copper chelates of the triketones were prepared.

In an effort to extend the versatility and usefulness of alkylations of dicarbanions of β-diketones, we have observed that 2-(chloromethyl)-2-methyl-1,3-dioxolane or 2-(bromomethyl)-2-methyl-1,3-dioxolane did not alkylate disodioacetylacetone (I) under the conditions in which simple alkyl halides (methyl iodide, butyl bromide, etc.[2]) alkylate I (see eq 1). That this lack of reactivity is a characteristic of these two compounds

$$\underset{\text{I}}{CH_3COCHCOCH_2}\overset{Na}{}\overset{Na}{} + RX \xrightarrow{H^+} CH_3COCH_2COCH_2R \quad (1)$$
R = methyl, ethyl, etc.

rather than a characteristic of ketal halides in general is discussed in the present paper.

The procedure involved conversion of acetylacetone to I by means of 2 molar equiv of sodium amide in liquid ammonia and treatment of this with 1 equiv of ketal halide (Scheme I). The results are summarized in Table I. It can be seen from Table I that, for n = 1, alkylation does not occur, but for II, n = 2, X = Br, alkylation does occur in poor yield. For n = 3, 4, and 5, X = Cl or Br, the reaction proceeds in much better yield. This indicates that, if the carbon bonded to the halogen is bonded to or near the ketal group, little or no alkylation reaction occurs because of the steric hindrance (II, n = 1, X = Cl or Br, similar to neopentyl halides), but, when the carbon bonded to halogen is further away from the ketal group, the steric hindrance decreases and allows the alkylation to proceed

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(2) C. R. Hauser and T. M. Harris, *J. Amer. Chem. Soc.*, **80**, 6360 (1958); K. G. Hampton, T. M. Harris, and C. R. Hauser, *J. Org. Chem.*, **30**, 61 (1965).