Oligomerization Stereochemistry of Vinyl Monomers. 8. β-Carbon Stereochemistry and Carbanion Structure in the Oligomerization of 2- and 4-Vinylpyridines

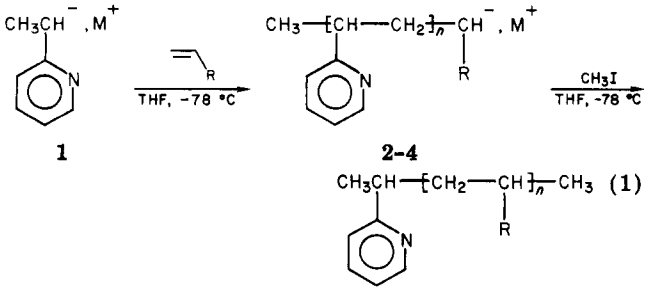
Thieo E. Hogen-Esch*[1] and Waylon L. Jenkins[2]

Department of Chemistry, University of Florida, Gainesville, Florida 32611.
Received January 5, 1981

ABSTRACT: The methylene stereochemistry of dimeric oligomerization products prepared by addition of (*E*)-2-vinylpyridine-β-*d*, (*Z*)-2-vinylpyridine-α,β-d_2, and (*E*)-4-vinylpyridine-β-*d* to alkali salts of 2-ethylpyridine was examined by 60- and 270-MHz ^{1}H NMR. The (trans overall) stereochemistry appeared to correlate with the relative proportion of geometric isomers of the initiator carbanion salt in the case of the deuterated 2-vinylpyridines. Thus, the addition of (*E*)-2-vinylpyridine-β-*d* to lithio-2-ethylpyridine in THF at −78 °C is highly stereoselective (90 ± 3%) and roughly correlates with the *E*/*Z* ratio of the lithio initiator salt. Subsequent addition of this monomer produces a similar stereochemistry, although the stereoselectivity of the second addition is lower than that of the first and third. It was also shown that the corresponding reaction of (*E*)-4-vinylpyridine-β-*d* with lithio-2-ethylpyridine is nonselective, presumably due to the absence of monomer coordination with the metal ion of the initiator carbanion pair. The results appear to suggest that in the anionic oligo- and polymerizations of vinyl monomers the carbanion geometry of the carbanion site is an important factor in the methylene stereochemistry along with the mode of monomer presentation.

Introduction

We recently reported[3,4] our studies on the stereochemistry of anionic oligomerization of 2- and 4-vinylpyridines in ethereal solvents, with emphasis on the effects of counterion size and coordination (eq 1).



1 2-4

$CH_3CH(-CH_2-CHR)_n-CH_3$ (1)

5-7

2, 5, n = 1; 3, 6, n = 2; 4, 7, n = 3

a, R = 2-pyridyl; b, R = 4-pyridyl

It was shown that in the presence of Li and Na as counterions, compound **5a** is formed with essentially 100% stereoselectivity and that the vinyl addition–methylation sequence of eq 1 followed by chromatographic separation likewise results in highly isotactic trimer **6a** and tetramer **7a** fractions.[5] With larger or more extensively coordinated counterions, these reactions were shown to be less stereoselective. The observations were shown to be consistent with a preferred diastereomeric ion pair that is conformationally rigid due to a coordination of the Li or Na ion by the lone pair of the penultimate 2-pyridine group. For the larger or more extensively coordinated cations, such an intramolecular chelation is incomplete or absent, and the lack of conformational rigidity of such an ion pair is most likely responsible for the significant decrease in methylation stereoselectivity.

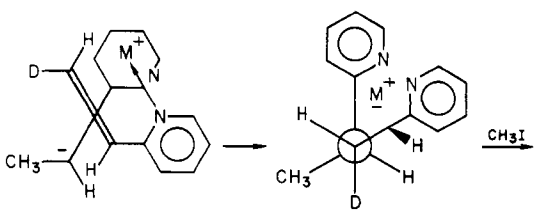
The stereochemistry of the α and β carbons established during anionic polymerization of vinyl monomers is possibly governed by different factors.[6,7] For instance, in the polymerization of isopropyl *cis*-α,β-dideuterioacrylate initiated by Grignard reagents, it was shown that small quantities of ether have a profound effect on the stereochemistry of the β carbon without affecting α-carbon stereochemistry of the isotactic (>95%) polymer. It was postulated[6,7] that β-carbon stereochemistry is most likely related to the monomer approach mode.

Table I
Dependence of (*E*)-1a/(*Z*)-1a Ratio on Cation Size and Coordination

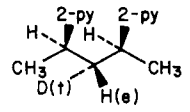
cation	solvent	% *E*	% *Z*	ΔG_{298}, kcal/mol	*K*
Li	THF	95	5	−1.81	19.00
Li	THF/TG	82	18	−0.94	4.60
Li	THF/[2.2.1]	36	64	−0.36	1.78
Na	THF	86	14	−1.13	6.10
Na	THF/TG	66	34	−0.41	1.90
K	THF	80	20	−0.86	4.00
K[a]	NH_3	45	55	−0.12	0.82

[a] At −40 °C; private communication from J. A. Zoltewicz.

Scheme I

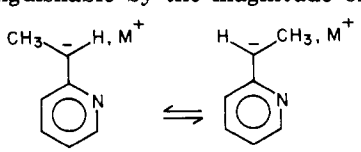


(*E*)-1a 2a'



(e)-H-13

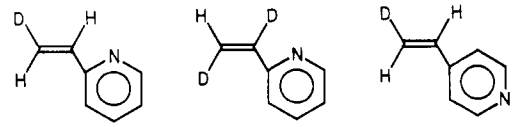
Recently, we reported the existence of *E* and *Z* isomers of **1a**, distinguishable by the magnitude of the H_α–H_4 coupling. It was shown[8,9] that the *E*/*Z* ratio is the thermodynamically determined and that the equilibrium is shifted toward the *E* form by small cations and the absence of extensive cation coordination (Table I). Preliminary results on the β-carbon stereochemistry of dimerization of **10** indicated, moreover, that the *E* ⇄ *Z* equilibrium may



(*E*)-1a ⇌ (*Z*)-1a (2)

0024-9297/81/2214-0510$01.25/0

be an important factor in the determination of this stereochemistry, as indicated in Scheme I. . Thus if (*E*)-**1a** reacts with **10**, with monomer coordination to the metal ion as shown, the resulting formation of **2a′** is expected to occur with stereoselective erythro (e) placement of hydrogen. The methylation of the lithio salt of **2a′** leads to *meso*-**5a** with very high (~99%) stereoselectivity, and the isolation of this product indeed shows highly stereoselective (90 ± 3%) placement of deuterium.[8] Since the stereochemistry of the carbanion carbon and methylene carbon is determined simultaneously, reaction of (*Z*)-**1a** in this manner would result in predominant threo (t) placement of hydrogen. We therefore decided to examine these phenomena in more detail. Of particular interest is the possible correlation of eq 2 with the erythro–threo placement of the remaining β proton of monomers **10** and **11**.



10 **11** **12**

In order to probe the validity of the proposed monomer approach mode, it is also of interest to examine the methylene stereochemistry of the addition of **12** to **1a** since coordination with counterion by this monomer during formation of the carbanion carbon–methylene carbon bond would seem unlikely. Finally, an evaluation of β-carbon stereochemistry of subsequent additions of **10** would seem important in order to better evaluate the relevance to the stereoregular polymerization of 2-vinylpyridine.

Experimental Section

(*E*)- and (*Z*)-2-Vinylpyridine-β-*d*. The deuterated 2-vinylpyridines were prepared by Cr^{II} reduction of 2-ethynylpyridine. The 2-ethynylpyridine synthesis was based on the one by Leaver et al.[10] 2-Vinylpyridine (160 g) in CCl_4 (250 mL) was added dropwise to a mechanically stirred, ice-cooled solution of Br_2 (88 mL) in CCl_4 (350 mL). The solution was decanted from a gummy mass and evaporated under reduced pressure at 40 °C to remove solvent and unreacted 2-vinylpyridine. The viscous crude dibromide (282 g) had the expected NMR with the following absorptions in CCl_4: doublet, δ 8.05 (1 H); triplet, δ 7.65 (1 H); multiplet, δ 7.2 (2 H); quartet, δ 5.25 (1 H); quartet, δ 4.0 (1 H). The quartets indicate a preferred conformation for the ABX system, resulting in differing coupling constants: J_{AB} = 9.3 Hz, J_{AX} = 4.9 Hz, J_{BX} = 10.2 Hz.

The crude dibromide (282 g) in *tert*-butyl alcohol (200 mL) was added, under N_2 during a 40-min period, to KOH pellets (250 g) in vigorously stirred, refluxing *tert*-butyl alcohol (450 mL) containing hydroquinone (3 g). After the addition was completed, the solution was refluxed and stirred for an additional 1.5 h, diluted with ether (500 mL), and filtered from an amorphous black solid. The filtrate was washed with water, and the aqueous phase was extracted twice more with ether. The ether solutions were combined, washed with water, dried over $MgSO_4$, and evaporated under reduced pressure to yield a dark brown liquid, which, upon distillation, produced 2-ethynylpyridine (16.2 g, 10.1% yield based upon 2-vinylpyridine), bp 74–76 °C (12 mmHg). The ^1H NMR spectrum in CCl_4 showed the following: doublet, δ 8.5 (1 H); multiplet, δ 7.4 (3 H); singlet, δ 3.35 (1 H). Lowering the pressure to 0.25 mmHg yielded a distillate at 80 °C which was a 70:30 mixture of (*Z*)-2-(2-bromoethenyl)pyridine and its *E* isomer as determined by NMR, with assignments based on cis and trans coupling constants.

2-Ethynylpyridine (10 g) and triethylamine (1 g) were vigorously stirred for approximately 0.5 h. The mixture was extracted twice with ether. The ether extracts were combined, evaporated under reduced pressure, and treated again with D_2O in the same manner. Analysis of the product by NMR showed the exchange to be essentially complete (98% D).

Reduction of the 2-ethynylpyridine-*d* was effected by Cr^{II}/H_2O, a reagent used for reducing a variety of acetylenes by Castro and Stephens.[11] To prepare a stock solution, hydrated $Cr_2(SO_4)_3$ (343 g) was dissolved in H_2O (2 L) while bubbling N_2 through the system. After purified zinc powder (89 g) was added, the mixture was stirred overnight in a flask equipped with a serum cap at room temperature. Filtration was not required, provided that the zinc was allowed to settle before tne solution was removed with a syringe. The clear blue solution had ca. 0.7 N Cr^{II} and pH ≃3.5. The stock solution was standardized by removing 2-mL aliquots and injecting into an aqueous solution containing excess $FeCl_3$ under nitrogen. The resulting solution was then titrated with 0.1017 N $Ce(SO_4)_2$ to a green phenanthroline end point. The reduction of 2-ethynylpyridine-*d* was carried out at room temperature under a nitrogen atmosphere. A 10% excess of Cr^{II} solution was transferred to a reaction flask containing the 2-ethynylpyridine. The addition of the Cr^{II} solution was accompanied by an immediate color change from the clear blue of Cr^{II} to the dark green of the Cr^{III}. Titration of aliquots confirmed that the reaction was complete almost immediately. The resulting solution was neutralized with $NaHCO_3$, which precipitated chromic hydroxide. After filtration, the solution was extracted three times with ether. The combined ether extracts were dried over $MgSO_4$ and evaporated under reduced pressure. After about 4 h of stirring over CaH_2, the liquid yielded upon vacuum distillation (*E*)-2-vinylpyridine-β-*d*. The NMR spectrum indicated the *E* and *Z* products to represent 91 and 7%, respectively, of the monomer. The remaining 2% represented undeuterated monomer.

(*Z*)-2-Vinylpyridine-α,β-d_2 was prepared similarly, except that 2-ethynylpyridine was reduced by Cr^{II} in D_2O. The percentages of *Z*, *E*, and undeuterated monomer were 58, 2, and 40%, respectively.

(*E*)-4-Vinylpyridine-β-*d*. This monomer was prepared by Cr^{II} reduction of 4-ethynylpyridine-*d*. Synthesis of 4-ethynylpyridine was achieved based on the procedure reported by Gray et al.[24] 4-Vinylpyridine hydrochloride (mp 240–243 °C) was prepared by bubbling HCl through a toluene solution of 4-vinylpyridine at −78 °C. The HCl was conveniently prepared by dripping concentrated H_2SO_4 onto NaCl in a flask warmed by a hot plate. The salt was collected by filtration and washed with hexane. 4-Vinylpyridine hydrochloride (68 g) in 350 mL of $CHCl_3$, cooled in an ice bath and vigorously stirred, was treated by dropwise addition of Br_2 (150 g). After the addition was completed, the reaction mixture was stirred for 1 h at ice-bath temperature and 1 h at room temperature. The mixture was diluted with ether and the precipitated orange oil was then treated with 300 mL of acetone to yield the white, crystalline hydrochloride salt of 4-vinylpyridine dibromide (122 g, mp 148–150 °C).

The salt (60 g) was treated with 10% Na_2CO_3, and the resulting base was extracted into ether. The ether extracts were dried over $MgSO_4$, concentrated under reduced pressure to 350 mL, and treated with triethylamine (22 g) in tetrahydrofuran. The mixture was stirred for 2 h at room temperature and then refluxed for 3 h. Triethylamine hydrobromide which had precipitated was filtered off and the filtrate evaporated to produce 35 g of a dark amber oil. The NMR spectrum of the oil in CCl_4 was consistent with the structure of 1-(4-pyridyl)-1-bromoethylene: multiplet, δ 8.53 (2 H); multiplet, δ 7.37 (2 H); doublet, δ 6.29 (1 H); doublet, δ 5.85 (1 H); $^2J_{AB}$ for the vinyl protons, 2.1 Hz.

The crude 1-(4-pyridyl)-1-bromoethylene (35 g) was added in 5-mL portions through a dropping funnel to an intimate mixture of 56 g of powdered KOH and 50 g of paraffin (mp 56–58 °C), which was magnetically stirred and heated by an oil bath to 160 °C under a reduced pressure of about 200 mmHg. The pressure was held at 200 mmHg for 2 min after each addition and then slowly reduced to 2 mmHg as the product distilled out of the reaction mixture. The product was collected in the form of white crystals on the side of the condenser and in the receiving flask, which was cooled with a dry ice/2-propanol bath. The product was recrystallized to yield 3.5 g of 4-ethynylpyridine (mp 95–97 °C) or 18% overall yield from 4-vinylpyridine. NMR spectrum: multiplet, δ 8.6 (2 H); multiplet, δ 7.20 (2 H); singlet, δ 3.22 (1 H). Exchange of the acetylenic proton was carried out as described for 2-ethynylpyridine.

Reduction was carried out with chromous ion in a manner similar to the reduction of 2-ethynylpyridine. The 4-ethynyl-

pyridine was dissolved in CH_3OD (1 g in 4 mL) prior to the reduction to produce a homogeneous system. Use of CH_3OH resulted in rapid exchange. The reduction showed an interesting temperature dependence. At room temperature, NMR analysis of the product showed the *Z* isomer to predominate by a factor of 60–40%, in contrast to the stereochemistry of reduction for 2-ethynylpyridine and other acetylenes previously reported.[11] An attempt to improve the stereoselection by cooling in an ice bath to 2 °C resulted in a 65:35 mixture, but under these conditions the *E* isomer predominated. The percentages of *E*, *Z*, and undeuterated isomer were 65, 35, and 2%, respectively.

Oligomerization of (*E*)-2-Vinylpyridine-β-*d* with Li as Counterion. *n*-Butyllithium (17 mL of a 1.6 M solution in hexane) was injected into the apparatus which had been flushed with argon for 15 min. The inlet was capped with a rubber septum and the apparatus was evacuated. The hexane was removed by distillation prior to condensing tetrahydrofuran (200 mL) in the reaction flask. 2-Ethylpyridine (2.5 mL) was distilled, in vacuo, into the flask, which was cooled to −78 °C in a dry ice/2-propanol bath. The solution was allowed to warm up slowly to room temperature to allow removal of the butane by distillation. After the system was again cooled to −78 °C, the ampule containing the (deuterated) monomer was opened. The monomer was distilled into the system during a period of 1–2 h. The distillation was slowed by cooling the monomer ampule with ice water. The reaction was terminated with CH_3I which had been dried over CaH_2 and degassed. The solvent was removed under reduced pressure, and the mixture of oligomers was dissolved in 10% HCl. The solution was washed with ether and neutralized with Na_2CO_3. The resulting base was extracted into ether. After drying over $MgSO_4$ and removal of the ether under reduced pressure, the 2,4-di(2-pyridyl)pentane was conveniently obtained by distillation (110–114 °C, 0.25 mmHg).

Isolation of Trimer 14 and Tetramer 15. Isolation of the trimer and tetramer was achieved by column chromatography. Neutral alumina of Brockman Activity I (80–200 mesh) which had been stored in a 110 °C oven overnight was used. The elution began with a 50/50 (vol/vol) mixture of ether and ligroin. The composition was varied until pure ether was the eluting solvent. A 50/50 mixture of ether and ethyl acetate was then used. Fractions containing relatively pure trimer and tetramer were obtained.

Oligomerization of (*E*)-2-Vinylpyridine-β-*d* with Li as Counterion (Tetraglyme Added). The reaction was carried out in a similar manner to that described above. The tetraglyme was added to the 2-ethylpyridyl salt at −78 °C prior to monomer addition.

Oligomerization of (*Z*)-2-Vinylpyridine-α,β-d_2 with K as Counterion. The reaction was carried out similarly to that using Li as counterion. The 2-ethylpyridyl carbanion was generated by distilling 2-ethylpyridine onto a tetrahydrofuran solution of potassium α-methylstyrene oligomer. The reaction was stopped by distilling D_2O into the reaction vessel. The 1,3-di(2-pyridyl)butane product was analyzed by 270-MHz NMR.

Cross Experiment: Lithium 2-Ethylpyridine with (*E*)-4-Vinylpyridine-β-*d*. The procedure used was the same as that for the anionic oligomerization of 2-vinylpyridine with Li as counterion. The reaction of *n*-BuLi with 2EP in THF at −78 °C generated Li2EP. Slow distillation of (*E*)-4-vinylpyridine-β-*d* onto the solution at −78 °C followed by the addition of D_2O completed the preparation. Following the usual workup, the product was vacuum distilled [105–110 °C (0.25 mmHg)] and analyzed by 270-MHz NMR.

Selectivity of Placement. The selectivity of placement was determined from the ^1H NMR spectra as follows:

1. The upfield and downfield areas corresponding to the β-carbon absorptions were determined and normalized to a total area of 1.
2. The total area actually represents $1 + f_H$ protons, where f_H is the fraction of undeuterated monomer, since each undeuterated monomer contributes to both regions. Each absorption was therefore corrected for undeuterated monomer by subtracting $f_H/(1 + f_H)$.
3. Corrected areas were again normalized to a total area of 1.
4. Correction for the proportion of *E* to *Z* deuterated monomer was made according to the equation $f_E X + (1 - f_E)(1 - X) = A_L$,

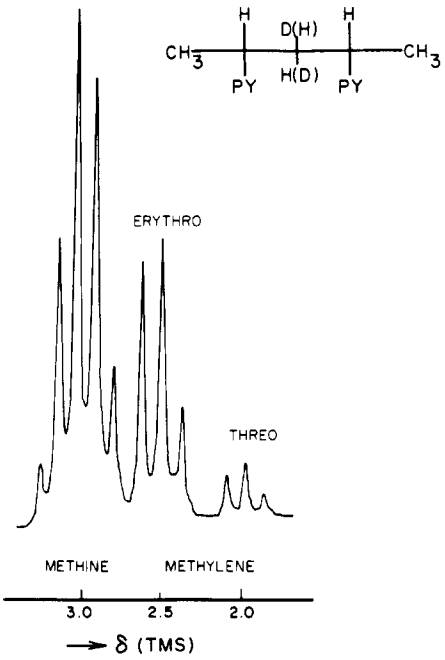


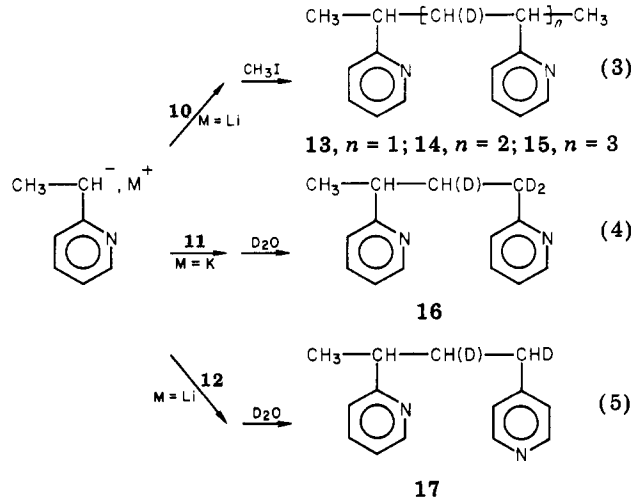
Figure 1. 60-MHz ^1H NMR spectrum of **13** in CCl_4.

where f_E is the fraction of *E* deuterated monomer, *X* is the fraction of preferred placement, and A_L is the corrected and normalized area for the largest absorption from step 3.

Results

Monomers **10–12** were prepared by an appropriate stereoselective Cr^{II} reduction of 2- and 4-ethynylpyridines.[10,11] The monomers were dried over CaH_2, vacuum distilled, and distilled once more on the vacuum line from CaH_2 (Experimental Section).

The oligomerization of 2-vinylpyridines initiated with lithium as counterion was carried out with (*E*)-2-vinylpyridine-β-*d* (91% isomeric purity) by in vacuo distillation of the monomer onto a vigorously stirred THF solution of initiator **1a** over a period of 1–2 h. The oligomerization was terminated by distillation in vacuo of CH_3I kept over CaH_2 onto the oligomerization mixture. The reactions of Li-**1a** with (*E*)-4-vinylpyridine-β-*d* (**12**) and of K-**1a** with **11** were carried out and terminated with D_2O in order to avoid the formation of a mixture of *meso*- and *rac*-**5a** caused by the lesser methylation stereoselectivity in these systems.[3] Products **13**, **16**, and **17** were obtained by distillation, and **14** and **15** were obtained by chromatography[12] (Experimental Section). The 60- and 270-MHz proton NMR spectra of the products are shown in Figures 1–5.



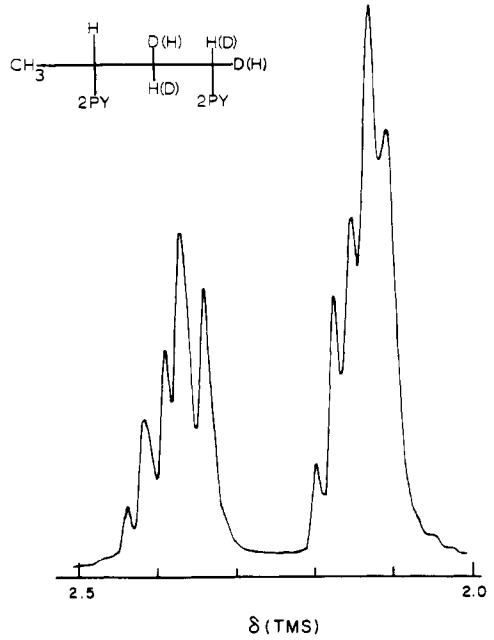


Figure 2. 270-MHz ^{1}H NMR spectrum of **16** in C_6D_6.

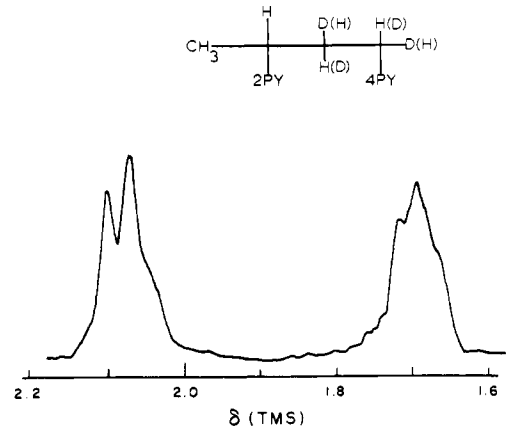


Figure 3. 270-MHz ^{1}H NMR spectrum of **17** in $CDCl_3$.

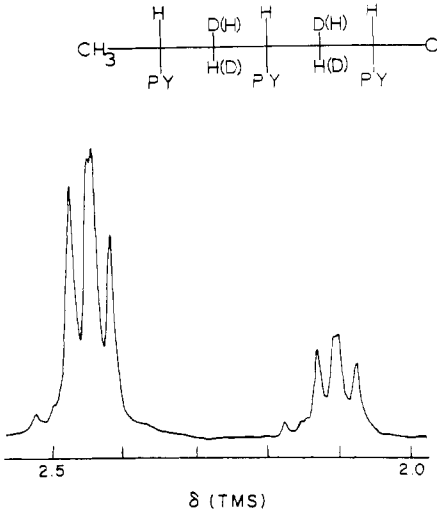


Figure 4. 270-MHz ^{1}H NMR spectrum of **14** in C_6D_6.

Assignments of threo (t) and erythro (e) protons in **13** were made on the basis of CH_2–CH coupling. Studies on both *meso*-2,4-dichloropentane[13] and *meso*-2,4-bis(carbomethoxy)pentane[14] have indicated that coupling with the methine proton is greater for the erythro proton than for the threo proton, in agreement with arguments based on the preferred conformation. In *meso*-2,4-di(2-pyridyl)-pentane, the corresponding coupling constants are 7.5 Hz for the downfield position and 6.5 Hz for the upfield position. In the conformations found to be prevalent for meso-disubstituted pentanes,[7] it appears that the erythro proton should be in a deshielding region with respect to the 2-pyridine ring. An unequivocal assignment in the *meso*-2,4-bis(carbomethoxy)pentane[14] has shown that the erythro proton absorbs downfield, and we will assume this to be the case for *meso*-**13** as well.

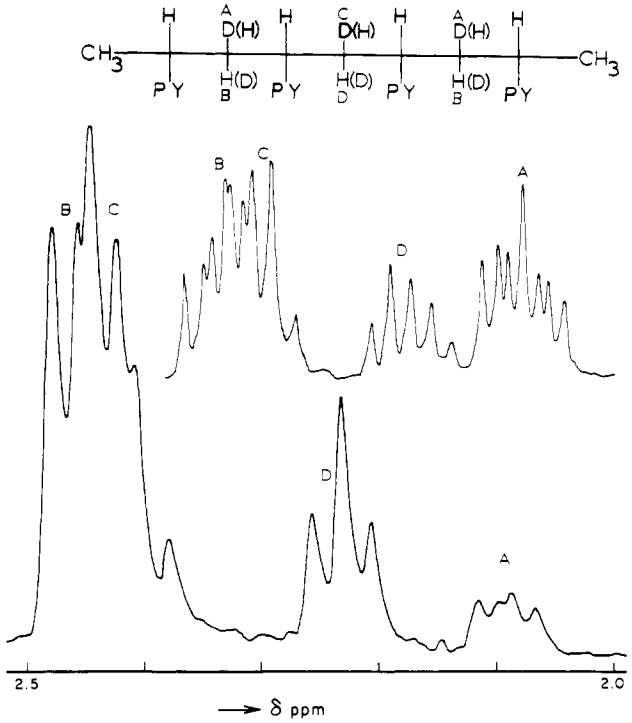


Figure 5. 270-MHz ^{1}H NMR spectrum of **15** in $CDCl_3$.

Effect of Cation Size. The 60-MHz NMR spectrum of *meso*-**13** (Figure 1) illustrates the high β-carbon stereoselectivity of the vinyl addition (91%), which is determined by taking into account the proportions of protonated and the isomeric deuterated monomers (Experimental Section). The 100-MHz spectrum of **16** is not sufficiently resolved to permit spectral analysis, but the 270-MHz spectrum allows convenient resolution (Figure 2). Keeping in mind that monomers differed in placement of deuterium, the large downfield absorption for **13** and the predominant upfield absorption for **16** most likely indicate that the preferred trans mode of addition is the same in both cases. After correction for monomer composition, the stereoselectivity for the Li- and K-initiated dimerizations was 91 and 77% as shown in Table II. Thus an increase in cation size appears to reduce the selectivity of monomer placement in a manner similar to the decrease in E/Z ratio in initiator 1.

Effect of Monomer Structure. The proposed coordination of the counterion by the nitrogen lone pair of the 2-vinylpyridine monomer during reaction would predict a dramatic decrease in the stereoselectivity of formation of the carbanion carbon–methylene carbon bond upon addition of 4-vinylpyridine. This is indeed found to be the case. Cross product **17** was prepared as described above. D_2O was used to terminate the corresponding anion in order to avoid the creation of a third chiral center. The 270-MHz spectrum (Figure 3) clearly resolves the two

Table II
β-Carbon Stereochemistry for the Anionic Oligomerization of 2- and 4-Vinylpyridines in THF at −78 °C

M+	solvent	anion	monomer	fraction trans addition
Li	THF	1a[b]	10	0.90 ± 0.03
	THF	2a[b]	10	0.66 ± 0.05
	THF	2a[b]	10	0.64 ± 0.10[a]
	THF	3a[b]	10	0.87 ± 0.10[a,c]
K	THF	1a	11	0.75 ± 0.05
Li	THF	1a	12	0.51 ± 0.06

[a] Calculated from Figure 5. [b] Deuterated monomer used in preparing these anions (eq 3). [c] Relatively large error due to determination of small A peak in addition to other errors (see Results).

methylene protons. Correction for monomer isomeric purity gives the result that the addition is not stereoselective within experimental error (Table II).

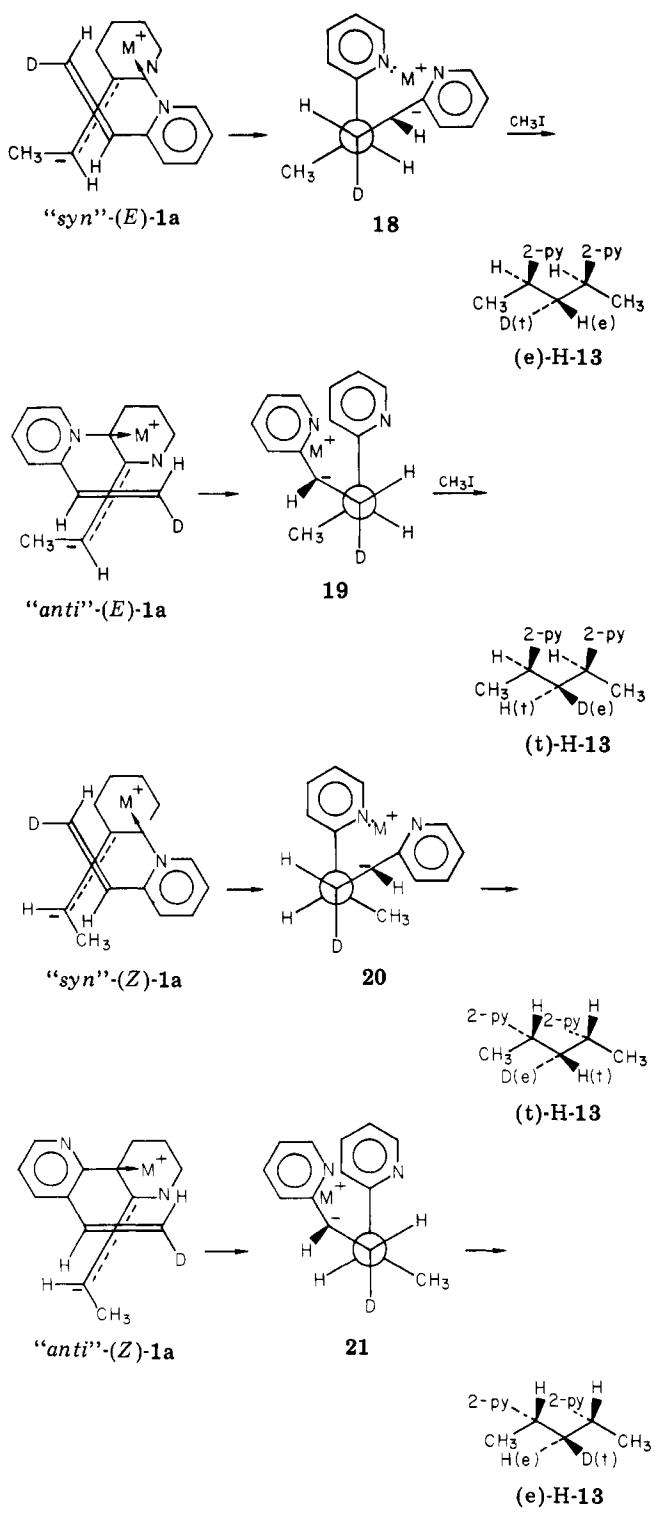
Effect of Degree of Oligomerization. Oligomerization of **10** initiated by Li-**1a** followed by methylation and column chromatographic separation yields **14** and **15**. The 270-MHz spectra of the expanded methylene portions are shown in Figures 4 and 5. The spectrum of the isotactic trimer shows clearly separated erythro and threo methylene protons, the two signals evidently having the same relative chemical shifts as in the dimer. From the ratio (73/27) and the isomeric and isotopic purity of monomer **10**, the predominant mode of addition is again trans, as in the case of the meso dimer, but the stereoselectivity is less (66%, Table II).

The spectrum of the protonated tetramer **7a** (Figure 5) shows three major absorptions in the ratio 3:1:2, corresponding, respectively, to the absorption of outer and inner methylene protons (B + C), inner methylene proton (D), and outer methylene protons (A). Comparison with the spectrum of **15** allows calculation of the absorption intensity of each of the four protons (A = 0.36, B = 1.64, C = 0.38, and D = 0.62 protons). Comparison with Figures 1 and 4 indeed confirms that the (downfield) B proton is erythro but that, surprisingly, the inner erythro (D) proton absorbs upfield, in agreement with a proposed assignment of Matsuzaki and Sugimoto[15] for isotactic poly(2-vinylpyridine) prepared by Grignard reagents in toluene. The observed reversal indicates that caution should be exercised in using simple model compounds such as **5a** as spectroscopic models of polymers. Figure 5 permits an evaluation of the β-carbon stereoselectivity of the second and third vinyl addition steps (Table II). The agreement with the second vinyl addition in the trimer is good, considering the sources of errors, such as the possible presence of minor amounts of other stereoisomers, errors in the isotopic and isomeric purities of the monomer, and the integration of the peaks. As is clear from the low intensity of the outer threo proton, the stereoselectivity of the third vinyl addition, like the first, is high and, together with differences in first and second additions, points up differences in stereochemical behavior of anions **1a**–**3a** (Discussion).

Discussion

The high stereoselectivity of formation of the asymmetric β carbon is of interest since it suggests a highly organized monomer approach mode. Although alternative modes of monomer reactions are conceivable, we believe that Scheme II is the simplest rationalization of our results. Thus a top-side approach "syn" to pyridine nitrogen with cation coordination to monomer would lead to the predominantly erythro placement of methylene hydrogen in

Scheme II



the reaction between **11** and **1a**. An alternative "anti" approach would result in a reversal of β-carbon stereochemistry.

The two modes of reaction of monomer **10** with (*E*)-**1a** are shown with the monomer approaching from the top side.[16] "Syn"-type approach appears likely to be favored for two reasons. First, the "anti" approach is expected to lead to a transition state which is not benefitting from an intramolecular coordination demonstrated in these systems.[3,4,17] Second, unfavorable CH_3–CH^-(2-pyridyl)butane gauche nonbonded interactions in **19** are not present in **18**.[3] As a result, the "anti"-type reaction should be substantially

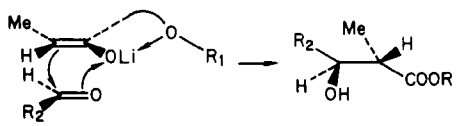
slower than the "syn" reaction. The situation is more complicated for the *Z* isomer. The "anti"-*Z* mode gives rise to **20** suffering from unfavorable butane gauche and CH_3–pyridine lone-pair interactions;[3] but the situation is not favorable for the "syn"-*Z* approach either, since in this case intramolecular coordination of metal ion by the 2-pyridyl group as shown in **18** and **20** is absent. The *E* isomer, therefore, is expected to be more reactive than the *Z* isomer (see below).

The effect of cation size and monomer structure on the stereochemistry of **5a** and **5b** indicates a pattern consistent with the above. For the addition of **10**, the *E*/*Z* ratio appears to correlate with β-carbon stereoselectivity (Table II). Thus for Li-**1a**, for which the *E*/*Z* ratio is 16, the addition of monomer **10** is highly (90%) β-carbon stereoselective. For potassium, the *E*/*Z* ratio declines and the e/t ratio of hydrogen placement drops accordingly (Table II).

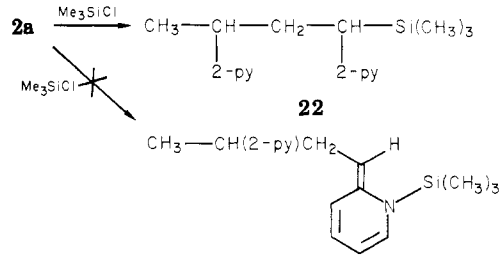
The results do not allow us to decide whether the observed 9 and 25% threo placements of hydrogen in **13** in the case of the lithium and potassium salts, respectively, are primarily due to participation of the *Z* form or to an "anti"-type reaction mode in the case of the *E* isomer. This is particularly difficult since with larger cations, reactions in the *E*-anti mode may become more pronounced because of the smaller role of intramolecular chelation.

The effect of degree of oligomerization on the stereochemistry of addition of **10** (Table II) shows that a similar mode of addition prevails for the dimeric anions **2a** and **3a**. Curiously, the stereoselectivity for the second addition (Table II) falls below that of the first addition. Some decrease in stereoselectivity is plausible since the butane anion immediately after reaction should exist as a *Z* anion[3,4] (see Scheme I). The stereoselectivity in the third addition step, however, is again similar to the first. Equilibration with the corresponding *E* isomer coupled with the greater reactivity of this isomer could very well lead to a predominant participation of the *E* isomer in the second and third addition steps. The reason for these differences in the degree of β-carbon stereoselectivity is not clear at present. It is possible that for anions **2a** and **3a** differences in the ratio or relative reactivity of *E* and *Z* isomers are responsible. NMR studies of anions **2a** and **3a** therefore would be very helpful in a further elucidation of the oligomerization stereochemistry. Unfortunately, we have so far been unable to obtain unambiguous NMR spectra of pure samples of anions **2a** or **3a**. The effect of monomer structure is more readily understood. Thus, consistent with the above mechanism, the addition of **12** is completely nonstereoselective. It is plausible, therefore, that both carbanion geometry and monomer presentation are important factors in determining β-carbon stereochemistry.

The proposed scheme is not unlike that proposed by Ireland[18] and others[19] for stereochemical control in the ester–enolate Claisen rearrangement. Another recent example is that by Meyers and Reider,[20] involving stereoselective aldol condensation of (*E*)-lithio enolates with aldehydes to form β-hydroxy esters:



In these cases, it was postulated that observed effects on stereochemistry most likely occur through an alteration in the *E*/*Z* ratio of the intermediate carbanions. In several instances[18,20-22] these ratios could be determined by trapping the enolates of other intermediates with trialkylsilyl chlorides. In our case such trapping was attempted, but reaction of butane anion **2a** with $(CH_3)_3SiCl$[23] resulted solely in a carbon silylation product **22** instead of the desired (*E*)- or (*Z*)-**23**.



(*Z*)-**23**

It should be stressed that although the *E*/*Z* ratio of intermediates does not play a direct role in α-carbon stereochemistry, a link between α and β stereochemistry may exist. Thus, intramolecular chelation in **18** should affect the *E*/*Z* ratio in this anion.

Such a correlation is not easily verified. Significant changes in α-carbon stereochemistry will result in the formation of racemic dyads, where a distinction between methylene hydrogens is not possible or complex and, therefore, difficult to analyze. Further experiments along these lines are in progress.

Conclusion

The above research indicates that anionic isotactic polymerization of 2-vinylpyridine in ethers takes place with overall trans addition of monomer. The *E* and *Z* geometric isomers, demonstrated for models of "living" poly(2-vinylpyridine), may play an important role in the determination of β-carbon stereochemistry. Thus, effects of solvents and cation size on this stereochemistry may, at least in some cases, be rationalized in terms of their effect on the ratio of the *E* and *Z* isomers of the carbanion intermediates. Monomer approach, moreover, is undoubtedly an important cofactor in the determination of β-carbon stereochemistry. This work also demonstrates an interesting reversal of relative chemical shifts of inner and outer erythro and threo methylene protons, indicating that caution should be exercised in using simple compounds such as 2,4-substituted pentanes as models of polymers.

Acknowledgment. Support of this research by the NSF DMR Polymers Program is gratefully acknowledged.

References and Notes

(1) Address correspondence to this author.
(2) Research Laboratories, Tennessee Eastman Co., Kingsport, TN 57662.
(3) Hogen-Esch, T. E.; Tien, C. F. *Macromolecules* **1980**, *13*, 207. *Ibid.* **1976**, *9*, 871.
(4) Tien, C. F.; Hogen-Esch, T. E. *J. Polym. Sci., Polym. Lett. Ed.* **1978**, *16*, 297. *Ibid.* **1979**, *17*, 281.
(5) Recent detailed investigations have indicated that vinyl addition is actually less stereoselective than methylation (Mathis, C.; Hogen-Esch, T. E., to be submitted for publication).
(6) Schuerch, C.; Fowells, W.; Yamada, A.; Bovey, F. A.; Hood, F. P.; Anderson, E. W. *J. Am. Chem. Soc.* **1964**, *86*, 4481.
(7) Bovey, F. A. "Polymer Conformation and Configuration"; Academic Press: New York, 1969; pp 54–70.
(8) (a) Jenkins, W. L.; Tien, C. F.; Hogen-Esch, T. E. *J. Polym. Sci., Polym. Lett. Ed.* **1978**, *16*, 501. (b) *Pure Appl. Chem.* **1979**, *51*, 139.
(9) (a) Jenkins, W. L.; Hogen-Esch, T. E., submitted for publication. (b) Jenkins, W. L. Ph.D. Thesis, University of Florida, 1978.
(10) Leaver, D.; Gibson, W. K.; Vass, J. D. R. *J. Chem. Soc.* **1963**, 6053.

(11) Castro, C. E.; Stephens, R. D. *J. Am. Chem. Soc.* **1964**, *86*, 4358.
(12) Separate reactions were run for the preparation of dimer and of trimer and tetramer. The product stereochemistry of dimer **13** was found to be the same regardless of the method of isolation.
(13) Doskocilova, D. *J. Polym. Sci., Part B* **1964**, *2*, 421.
(14) (a) Yoshino, T.; Korniyama, J.; Shinomiya, M. *J. Am. Chem. Soc.* **1964**, *86*, 4482. (b) Yoshino, T.; Shinomiya, M.; Kimoyama, J. *Ibid.* **1965**, *87*, 387.
(15) Matsuzaki, K.; Sugimoto, T. *J. Polym. Sci., Part A-2* **1967**, *5*, 1320.
(16) Bottom-side monomer approach leads to enantiomeric products in each case.
(17) (a) Fisher, M.; Szwarc, M. *Macromolecules* **1970**, *3*, 23. (b) Tardi, M.; Rouge, D.; Sigwalt, P. *Eur. Polym. J.* **1967**, *3*, 85.
(18) Ireland, R. E.; Mueller, R. H.; Willard, A. K. *J. Am. Chem. Soc.* **1976**, *98*, 2868.
(19) Heathcock, C. H.; Buse, C. T.; Kleschiek, W. A.; Pirrung, M. C.; Sohn, J. E.; Lampe, J. *J. Org. Chem.* **1980**, *45*, 1066.
(20) Meyers, A. I.; Reider, P. J. *J. Am. Chem. Soc.* **1979**, *101*, 2501.
(21) Kleschick, W. A.; Buse, C. T.; Heathcock, C. H. *J. Am. Chem. Soc.* **1977**, *99*, 247.
(22) Fellman, P.; Dubois, J. E. *Tetrahedron* **1978**, *34*, 1349.
(23) Meverden, C. C.; Hogen-Esch, T. E., to be submitted for publication.
(24) Gray, A. P.; Kraus, H.; Heilmeier, D. E.; Shiley, R. H. *J. Org. Chem.* **1968**, *33*, 3007.

Triphase Catalysis. Influence of Percent Ring Substitution on Active-Site Mobility, Macroenvironment, Microenvironment, and Efficiency[1]

Noritaka Ohtani,[2] Charles A. Wilkie, Alok Nigam, and Steven L. Regen*

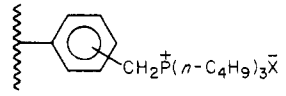
Department of Chemistry, Marquette University, Milwaukee, Wisconsin 53233.
Received September 25, 1980

ABSTRACT: Microporous cross-linked polystyrenes (1% divinylbenzene) bearing methylenetri-*n*-butylphosphonium chloride (**1a**, 17% ring substitution (prs); **1b**, 52 prs) or mesylate groups (**2a**, 17 prs; **2b**, 52 prs) have been examined by ^{13}C NMR spectroscopy under triphase conditions. Pendant group mobility was high in **1a** and **2a** and was insensitive to the concentration of sodium chloride in the exterior aqueous layer; for **1b** and **2b** the mobility remained high but was inversely related to the salt concentration. Qualitatively, these results closely correlate with analysis made of the imbibed solvents; both show that (1) **1b** is physically responsive to changes in the salt concentration used whereas **1a** is not, (2) **1a** responds well to organic solvents and is insensitive to water, while the reverse is true for **1b**, and (3) when saturated sodium chloride solutions are used, pendant group mobility and polymer swelling are maximum under triphase conditions. Resins **1a** and **1b** have also been evaluated as triphase catalysts for chloride ion displacement on *n*-decyl methanesulfonate and for alkylation of β-naphthoxide by benzyl bromide. Over a wide range of salt concentrations, the amount of imbibed water in **1a** was low and nearly constant; its activity for chloride ion displacement was high and, within experimental error, constant. For **1b**, an increase in the salt concentration substantially decreased the water uptake and raised its activity. Whereas **1a** led to predominant O-alkylation of β-naphthoxide, **1b** afforded mostly C-alkylation.

Introduction

The precise relationship between macrostructure, microenvironment, and activity of polymer-based triphase catalysts is poorly understood.[3] Although kinetic studies have proven valuable in defining the synthetic utility of certain triphase reactions, they have provided little mechanistic insight. Recent attempts to rationally design new and more active catalysts have focused primarily on the nature of the catalytic site, where close analogy has been made to phase-transfer catalysis.[4] Little consideration, however, has been given to the *concentration* of these sites within the polymer.[5]

In the present work we closely examine the physical and chemical consequences of changing the active-site concentration in a typical triphase catalyst. For this purpose, we have selected polymers **1a**, **1b**, **2a**, and **2b**.[6,7] Our reason for choosing these polymers was fourfold. First, phosphonium-based resins are among the most active triphase catalysts.[7-10] Second, these polymers span the range of loadings which have been employed in most synthetic applications. Third, low cross-link densities provide maximum catalyst efficiencies;[7,8] they also afford reasonably narrow ^{13}C NMR line widths in solvent-swelled resins, making spectral analysis and evaluation of site mobility possible using conventional instrumentation.[11] Fourth, the mesylate ion in **2a** and **2b** allows for examination of ionically as well as covalently attached sites.



functionalized microporous polystyrene-1% divinylbenzene
1a, 17% ring substitution; X = Cl
b, 52% ring substitution; X = Cl
2a, 17% ring substitution; X = OSO_2CH_3
b, 52% ring substitution; X = OSO_2CH_3

$C_6H_5CH_2\overset{+}{P}(n\text{-}C_4H_9)_3\bar{X}$

3, X = Cl
4, X = OSO_2CH_3

Data which we now present from ^{13}C NMR, swelling, product distribution, and kinetic analysis show that the percent ring substitution has a substantial influence on the mobility, macroenvironment, microenvironment, and catalytic efficiency of tri-*n*-butylphosphonium groups attached to cross-linked polystyrene under triphase conditions.

Results and Discussion

^{13}C NMR Characterization. The procedures used for obtaining ^{13}C NMR spectra under biphase and triphase conditions were unexceptional and are described in the Experimental Section. Table I summarizes observed line widths, $\Delta\nu_{1/2}$, of the mesylate and pendant methyl carbons measured at full-width at half-height. These data provide direct information concerning the mobility of the active sites.[12] Also reported in this table are appropriate chemical shifts which reflect the microenvironment experienced by

0024-9297/81/2214-0516$01.25/0