phosph(on)ates and a recent report of $Cs_6[(OPO_3)_2W_5O_{15}]\cdot 7.5H_2O$[4] is shown in Figure 1.

The IR spectrum of I is unchanged when it is dissolved in acetonitrile, and ultracentrifugation measurements[8] of such solutions (0.13–0.45 mM) indicate a molecular weight of 1900 ± 200[9] ("bare" anion formula weight, 1470). Proton and phosphorus-31 NMR spectra are consistent with the C_2 structure of Figure 1,[10] but the 27.12-MHz ^{17}O NMR and 10.42-MHz ^{183}W NMR[11] spectra shown in Figure 2 point to fluxional behavior. The ^{183}W spectrum consists of a single line (δ_{306}–155.9 from 1.0 M Na_2WO_4 in D_2O) split into a 1:2:1 triplet by two equivalent ^{31}P nuclei (J = 1.95 Hz) and is consistent only with an intramolecular exchange process.[12] The nature of the molecular rearrangement can be described as follows. It has been pointed out by Day and Klemperer[13] that the P_2M_5 structure of Figure 1 incorporates weak M–O(P) bonds and that if the structure is dissected at these bonds, the oxometalate portion can be viewed as a ring of five corner-shared MO_4 tetrahedra. We note that, if the five bridging oxygens are ignored, such a ring is a topological analogue of cyclopentane and, further, that the metal atom positions fall very close to those describing an "envelope" conformer (four coplanar atoms and one atom out of the plane).[14] The five possible envelope forms of cyclopentane are readily interconverted by a ring pseudorotation, and we propose an analogous mechanism for the tungstophosphonate.[15] In the course of this process the RPO_3 groups must undergo a concerted oscillation (or rotation) about the R–P axes in order to interchange the positions of the phosphonate oxygens with respect to the metal atoms. Although each of these oxygens formally changes from doubly to triply bridging during the pseudorotation of the ring, we view this as a continuous change with no abrupt bond breaking or formation.

Further variable temperature and labeling experiments involving these complexes and related molybdates in aqueous and nonaqueous solution are in progress.

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(8) Sedimentation equilibrium method using a Beckmann Model E ultracentrifuge with UV optics and photoelectric scanner and operating at 20 000 rpm.

(9) Ultracentrifugation of aqueous solutions of the potassium salt (0.1 M formate buffer, pH 3.5) gave concentration-dependent results which indicated that dissociation of the heteropolyanion upon dilution[5] yielded an isopolytungstate with a molecular weight of ca. 3500.

(10) (a) ^1H NMR (90 MHz): δ 8.36–8.10 (m, 2, *o*-phenyl protons), 7.49–7.43 (m, 3, *m*- and *p*-phenyl protons); $(C_4H_9)_3NH^+$ multiplets at ca. δ 0.83–0.99, 1.19–1.76, 2.90–3.11. The spectrum of $C_6H_5PO_3H_2$ in CD_3CN shows all protons as an unresolved multiplet at δ 7.93–7.49. (b) $^{31}P\{^1H\}$ NMR (36.44 MHz): δ +16.4.

(11) (a) The first application of ^{183}W NMR spectroscopy to heteropolytungstates was reported by: Acerete, R.; Hammer C. F.; Baker, L. C. W. *J. Am. Chem. Soc.* **1979**, *101*, 267. (b) Bruker WM250. Recording conditions: 15-mm tube, multinuclear probe head, deuterium lock; pulse angle 50 μs (ca. 60°), 1-S delay, temperature 235–306 K.

(12) The structure of Figure 1 should give three ^{183}W resonances (2:2:1) with complex ^{183}W–^{31}P coupling. No coupling would be observed if the exchange were intermolecular. Although the ^{17}O spectrum shown in Figure 2 indicates the presence of water, we have also recorded identical ^{17}O and ^{183}W spectra in anhydrous CD_2Cl_2. A water exchange process similar to that observed in the hexametalloarsonates[1] is thus ruled out.

(13) Day, V. W.; Fredrich, M. F.; Klemperer, W. G.; Shum, W. *J. Am. Chem. Soc.* **1977**, *99*, 952.

(14) On the basis of the dimensions of six independent molecules,[9b,d-f] four of the metal atoms in P_2M_5 structures lie within 0.06 ± 0.02 Å of a least-squares plane and the fifth metal atom lies 0.63 ± 0.11 Å out of the plane. Because of the effective C_2 symmetry of the anion there are two ways of choosing the "coplanar" atoms; in Figure 1 these are 1, 2, 3, and 4 *or* 2, 3, 4 and 5. The metal–metal distances around the ring are 3.37 Å except between atoms 1 and 5 (3.68 Å). The nonplanar structure for cyclopentane is normally attributed to the effects of repulsions between hydrogens. In the case of the metallophosphonates the structure is imposed by the dimensions of the RPO_3 group.

(15) Pseudorotation of cyclopentane (Kilpatrick, J. E.; Pitzer, K. S.; Spitzer, R. *J. Am. Chem. Soc.* **1947**, *69*, 2483. Pitzer, K. S.; Donath, W. E., *Ibid.* **1959**, *81*, 3213) is unhindered and can be viewed as a molecular vibration (Anet, F. A. L.; Anet, R. "Dynamic Nuclear Magnetic Resonance Spectroscopy"; Jackman, L. M., Cotton, F. A., Eds.; Academic Press: New York 1975; p 543). Pseudorotation of the polytungstate on the other hand should not be activationless. The ^{183}W NMR spectrum of I in acetonitrile is unchanged at 235 K (temperature limited by solvent) which indicates that $\Delta G^{\ddagger} < 14$ kcal mol^{-1}. Further delineation of the exchange by measurements in other solvents and at lower temperatures is planned.

Substituent Control of the Poly(C)-Directed Oligomerization of Guanosine 5′-Phosphoroimidazolide

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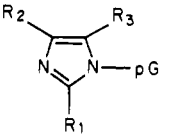
The efficiency of the oligomerization of guanosine 5′-phosphorimidazolide (**1**) in aqueous solution is greatly increased in the presence of poly(C) under conditions that permit the formation of organized helical structures. However, it is only in the presence of Zn^{2+} or Pb^{2+} that we could detect long oligomeric products.[1-3] We now report that, even in the absence of Zn^{2+} or Pb^{2+}, the poly(C)-directed oligomerization of a closely related phosphorimidazolide **2** at pH 7 and 0 °C gives long, predominantly 3′,5′-linked oligomers in good yield.



1, $R_1 = R_2 = R_3 = H$
2, $R_1 = Me$; $R_2 = R_3 = H$
3, $R_1 = R_3 = H$; $R_2 = Me$ (or $R_1 = R_2 = H$; $R_3 = Me$)
4, $R_1 = Et$; $R_2 = R_3 = H$

The ^{14}C-labeled imidazolides **1**–**4** were prepared by procedures described previously.[4] The oligomerization reactions were allowed to proceed in 2,6-lutidine–nitric acid buffers (pH 7.0 at room temperature, 0.4 M) at 0 °C for 14 days. In all cases the reaction mixtures remained homogeneous. The products of the reaction were separated by descending paper chromatography on Whatman 3MM paper using *n*-propanol, concentrated ammonia, and water (55:10:15) as eluant. Yields of products were determined by running the chromatograms through a radiochromatogram scanner with integrator.

The results of these experiments are summarized in Table I. The phosphorimidazolide **2** condenses far more efficiently than the closely related derivates **1**, **3**, and **4**. This efficient condensation is dependent on the presence of a poly(C) template. The efficiency increases with the concentration of reactants, presumably because the stability of the helix increases at higher concentrations of reagents.

The mean chain length of the oligomers remaining at the origin of the chromatograms was determined as described previously.[2,3] In the most concentrated solution (Table I, row 3) the imidazolide **2** yielded oligomers with mean chain length 14. The mean chain lengths of the oligomers derived from **1**, **3**, or **4** were 4, 6, 6, respectively.

The details of the product distributions were examined by HPLC on RPC5 as previously described.[2,3] Samples were degraded exhaustively with pancreatic ribonuclease before application

(1) R. Lohrmann, P. K. Bridson, and L. E. Orgel, *Science* (*Washington, D.C*), **208**, 1464 (1980).
(2) P. K. Bridson and L. E. Orgel, *J. Mol. Biol.*, **144**, 567 (1980).
(3) R. Lohrmann and L. E. Orgel, *J. Mol. Biol.*, **142**, 555 (1980).
(4) (a) T. Mukaiyama and M. Hashimoto, *Bull. Chem. Soc. Jpn.*, **44**, 2284 (1971). (b) R. Lohrmann and L. E. Orgel, *Tetrahedron*, **34**, 853 (1978); **35**, 566 (1979) (errata).

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Table I. Percentage Yield of Material at Origin (Tetramer and Longer)[a]

no.	concn of monomer, M	$R_1 = H$, $R_2 = H$	$R_1 = Me$, $R_2 = H$	$R_1 = H$, $R_2 = Me$	$R_1 = Et$ $R_2 = H$
1	0.0125	13	46	6	9
2	0.025	32	74	23	20
3	0.05	39	89	45	34
4	0.05 (no template)	0	0	0	0

[a] 2,6-Lutidine–HNO_3 buffer, pH 7.0, 0.4 M; $NaNO_3$, 0.4 M; $Mg(NO_3)_2$, 0.8 M. Imidazolide poly(C) ratio is 1:2. Yields after 14 days at 0 °C.

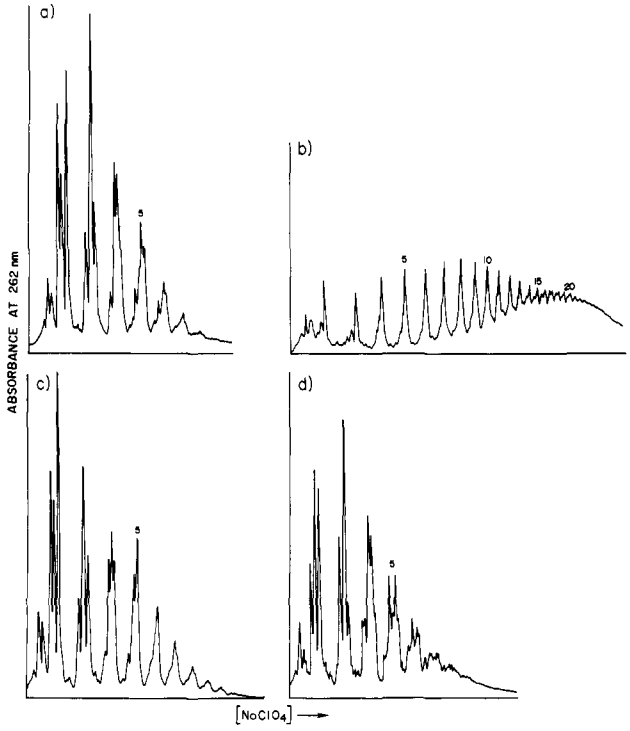

Figure 1. HPLC elution profile of guanosine-5′-phosphorimidazolide derivatives on a poly(C) template after 14 days (Table I, row 3). (a) $R_1 = R_2 = R_3 = H$; (b) $R_1 = Me$, $R_2 = R_3 = H$; (c) $R_1 = Et$, $R_2 = R_3 = H$; (d) $R_1 = R_3 = H$, $R_2 = Me$ (or $R_1 = R_2 = H$, $R_3 = Me$). For reaction conditions see footnote to Table I.

on the column. The all 3′,5′-linked oligomers were identified by cochromatography with authentic samples obtained by degrading poly(G) with ribonuclease P_1.

Elution profiles of the products obtained from the four imidazolides under identical conditions are shown in Figure 1. It is clear that substantial amounts of oligomers up to the 50-mer are obtained from **2**, while the oligomers obtained from **1**, **3**, and **4** are much shorter. Furthermore, the isomeric purity of the products from **2** is greater than that from any other imidazolide, as revealed by a comparison of peak height corresponding to the all 3′,5′-linked compounds with the peaks to the left of them on the HPLC elution profile. We confirmed that the products from **2** are almost exclusively 3′,5′ linked by degrading a sample with ribonuclease T_2 before application to the column. Negligible amounts of material longer than trimer were detected.

The greatly enhanced yield of oligomers obtained in the reaction of **2** in the presence of poly(C) and the extreme sensitivity of the efficiency and regioselectivity of the reactions to minor changes in the nature of the imidazole moiety are unusual for an organic condensation reaction in solution. Presumably, the rigid orientation of monomers imposed by the poly(C) template makes possible a degree of specificity which is rarely encountered, except with highly constrained reactants or in enzyme-catalyzed reactions. We believe that the 2-methyl group controls the detailed structure of the exterior of the helix so as to bring the P–N bond in line with 3′-O···P direction. Larger substituents at the 2-position or a 4-(5-)methyl group lead to a less favorable geometry.

We have also studied the time course of the template-directed reaction of **2** at various temperatures. The terminal yield falls from 89% to 54% and the half-life of the reaction from 4 days to 18 h as the temperature increases from 0 to 20 °C. In other experiments we found that the concentration of Na^+ and Mg^{2+} ions profoundly affects the efficiency and regioselectivity of the reaction, as revealed by the HPLC profile of the products. In solutions containing 0.4 M $NaNO_3$ and 0.2 M $Mg(NO_3)_2$, for example, we find very sharp peaks corresponding to all 3′,5′-linked oligomers up to the 20-mer, while in solutions containing 0.4 M $NaNO_3$ and 1.2 M $Mg(NO_3)_2$ we observe much broader peaks corresponding to oligomers at least as long as the 40-mer but containing more 2′,5′ linkages.

In a previous study of a related Zn^{2+} condensation of **1** on poly(C), we concluded, tentatively, that the Zn^{2+} ion functions by changing the geometry of the helix rather than by activating the 3′-OH group.[2] The results reported here strengthen that conclusion, since they show that orientation alone can greatly increase the efficiency of the reaction.

The sensitivity of the reaction to minor changes in the concentration of reactants and metal ions may have significance in the context of the chemistry of the prebiotic earth. It suggests that short peptides that interacted with polynucleotides might have had profound effects on the efficiency and regiospecificity of the earliest prebiotic template-directed replication reactions.

Full details of these and related reactions will be reported in due course.

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Ketone Methylenation with Optical Resolution. Total Synthesis of the Ginseng Sesquiterpene (−)-β-Panasinsene and Its Enantiomer

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(−)-β-Panasinsene (**1**) is a principal component of the volatile oil from the root of ginseng (*Panax ginseng*) which is highly valued in Chinese folk medicine. The compound was identified and found to be present in both fresh and dried ginseng by Yoshihara and Hirose in 1975.[1] The synthesis of (±)-**1** has recently been reported by McMurry and Choy.[2] We were intrigued primarily by the unique 4-5-6 fused tricyclic system of **1** and secondly by the comment of McMurry and Choy that "total synthesis of panasinsenes turned out to be a considerably more difficult task than we had originally thought and more than a few synthetic plans came to naught". The most apparent penult in the synthesis of **1** is ketone **2** which McMurry and Choy found to be "inert to methylenetriphenylphosphorane in DMSO". This lack of reactivity of ketone **2** in the Wittig reaction indicated to us that **2** would be a good vehicle for demonstrating the efficacy of a new methylenation–resolution scheme based on sulfoximine chemistry.

Conjugate addition of 4-methyl-3-pentenylmagnesium bromide[3] to 3-methyl-2-cyclohexenone in the presence of 5 mol % of copper(I) bromide/dimethyl sulfide complex in tetrahydrofuran (THF) at 0 °C followed by trapping of the intermediate enolate

(1) Yoshihara, K.; Hirose, Y. *Bull. Chem. Soc. Jpn.* **1975**, *48*, 2078.
(2) McMurry, J. E.; Choy, W. *Tetrahedron Lett.* **1980**, 2477. Their synthesis involved intramolecular cuprous triflate catalyzed photocyclization of 2-methylene-3-(4-methyl-3-pentenyl)-1-cyclohexanol (elaborated from 2-methylcyclohexanone), oxidation of the photoproduct to ketone **2**, addition of methyllithium, and dehydration to a mixture of α- and β-panasinsenes.
(3) Julia, M.; Julia S.; Guegan, R. *Bull. Soc. Chim. Fr.* **1960**, 1072.

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