$$\text{Ta(BH}_4)\text{H}_2(\text{PMe}_3)_4 + 3\text{CO} \xrightarrow[\text{0.25 h, 25 °C}]{\text{C}_6\text{H}_{14}}$$
$$\underset{\mathbf{1}}{}$$

$$\underset{\mathbf{3}}{\text{Ta(BH}_4)(\text{CO})_3(\text{PMe}_3)_3} + \text{H}_2 + \text{PMe}_3 \quad (3)$$
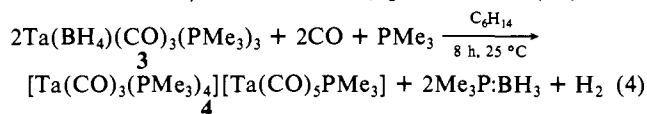
at 2420, 2400, and 2140 cm^{-1} (benzene) and 1950, 1850, and 1830 cm^{-1} (hexane) which were assigned as B–H and C–O stretching frequencies, respectively. In addition, we were able to locate a –BH$_3$ deformation mode at 1115 cm^{-1} in the Nujol mull spectrum. The frequencies identified with the BH$_4$ moiety are indicative of monodentate coordination.[10] The room temperature ^{1}H NMR spectrum of **3** in toluene-d_8 shows a broad phosphine methyl resonance at δ 1.11 and a broad quartet ($^1J_{^{11}BH}$ = 82.8 Hz) at δ 0.05. The latter is typical of a fluxional tetrahydroborate ligand.[10] When the sample is cooled to –80 °C, the phosphine methyl resonance splits into two signals and the BH$_4$ resonance collapses to a broad hump.[18] The C–O stretching frequencies and low-temperature ^{1}H, ^{13}C, and ^{31}P NMR spectra of **3** are quite similar to those observed for the structurally characterized capped trigonal-prismatic complex TaCl(CO)$_3$(PMe$_3$)$_3$.[19] As such, we assign structure C to **3**.

C
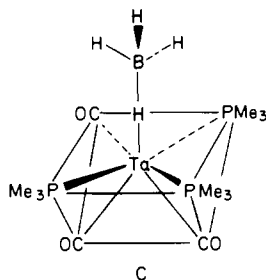
If **3** is not isolated in reaction 3, it slowly converts into an orange crystalline solid over the course of ca. 8 h. This product has been identified (vide infra) as the double salt [Ta(CO)$_3$(PMe$_3$)$_4$][Ta(CO)$_5$PMe$_3$] (**4**)[20] and the yield (based on **1**), after recrystallization from THF/hexane, is 85% (eq 4). The ^{31}P{^{1}H} NMR

$$\underset{\mathbf{3}}{2\text{Ta(BH}_4)(\text{CO})_3(\text{PMe}_3)_3} + 2\text{CO} + \text{PMe}_3 \xrightarrow[\text{8 h, 25 °C}]{\text{C}_6\text{H}_{14}}$$
$$\underset{\mathbf{4}}{[\text{Ta(CO)}_3(\text{PMe}_3)_4][\text{Ta(CO)}_5\text{PMe}_3]} + 2\text{Me}_3\text{P:BH}_3 + \text{H}_2 \quad (4)$$

spectrum of **4** (THF-d_8, 25 °C) exhibits three resonances. The singlet at δ –30 and the AX$_3$ pattern (δ_A +10.4, δ_X –33.5, J_{AX} = 24.4 Hz) are assigned to the anion and cation, respectively. The IR spectrum of **3** in THF shows the expected five-band pattern in the C–O stretching region: 1980, 1965, 1870, 1850, and 1825 cm^{-1}.

Single crystals of **3** were grown by slow diffusion of hexane into THF solutions at –40 °C and the structure was determined from X-ray diffraction data collected at –160 °C.[21] In the solid state, the compound is composed of discrete [Ta(CO)$_3$(PMe$_3$)$_4$]$^+$ cations and [Ta(CO)$_5$PMe$_3$]$^-$ anions and there are no unusual interion contacts. An ORTEP drawing of the cation, a capped octahedral complex, is shown in Figure 2. The view is down the approximate

3-fold axis and the methyl groups on P(25), which caps the trigonal Ta(CO)$_3$ face, have been omitted for clarity.[22] Selected structural data: Ta–C(33,35,37)$_{av}$, 2.07 [1] Å; Ta–P(17,21,29)$_{av}$, 2.642 [5] Å; Ta–P(25), 2.555 (3) Å; P(25)–Ta–C(33,35,37)$_{av}$, 72.0 [4]°; P(25)–Ta–P(17,21,29), 123.0 (1)°, 114.6 (1)°, and 131.9 (1)°.

An ORTEP drawing of the octahedral [Ta(CO)$_5$PMe$_3$]$^-$ anion is also shown in Figure 2. The equatorial Ta–C bond lengths, which average 2.10 [1] Å, are comparable to those found[23] in [PPN][Ta(CO)$_6$], i.e., 2.083 (6) Å. The axial Ta–C(14) bond length, 2.03 (1) Å, is significantly shorter, consistent with the expected trans effect.[24] Additional structural data: Ta–P(2), 2.568 (3) Å; P(2)–Ta–C(6,8,10,12,14), 91.9 (3)°, 87.2 (3)°, 84.8 (3)°, 94.6 (3)°, and 174.3(3)°.

We have shown here that tetrahydroborate complexes are useful precursors in organotantalum chemistry. Future papers in this series will expand on this theme and provide further details on the reactions and compounds described above.

Supplementary Material Available: Atomic positional and thermal parameters for compound **4** (2 pages). Ordering information is given on any current masthead page.

(22) (a) The sites occupied by the CO and PMe$_3$ ligands as well as the angles subtended from the capping phosphorus atom are in excellent agreement with the theoretical predictions of Hoffmann et al.[22b] (b) Hoffmann, R.; Beier, B. F.; Muetterties, E. L.; Rossi, A. R. *Inorg. Chem.* **1977**, *16*, 511.
(23) Calderazzo, F.; Englert, U.; Pampaloni, G.; Pelizzi, G.; Zamboni, R. *Inorg. Chem.* **1983**, *22*, 1865.
(24) A structural trans effect of this magnitude is not seen in the isoelectronic tungsten analogue. See: Cotton, F. A.; Darensbourg, D. J.; Kolthammer, B. W. S. *Inorg. Chem.* **1981**, *20*, 4440.

Thermocontrol of Ion Permeation through Ternary Composite Membranes Composed of Polymer/Liquid Crystal/Amphiphilic Crown Ethers

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Biological membranes are composed of various kinds of phospholipids, cholesterols, and proteins and the fundamental functions such as permeation and selectivity are frequently associated with the gel–liquid crystal phase transition. Recently, totally synthetic amphiphiles which contain a molecule with both a hydrophobic group of two alkyl chains and an appropriate hydrophilic group have been shown to also form oriented aggregates in water with a phase diagram very similar to that of natural phospholipids.[3,4] Therefore, they may be regarded as a new class of biomembrane models. To apply these new materials to practical systems without losing their membrane mimetic functions, one has to develop methods to polymerize or immobilize them in polymer matrices.[5–10] Composite membranes in which the ar-

(18) Anal. Calcd for Ta(BH$_4$)(CO)$_3$(PMe$_3$)$_3$: C, 28.37; H, 6.15. Found: C, 28.15; H, 6.20. ^{1}H NMR (ppm, C$_7$D$_8$, 360 MHz, –80 °C) δ 1.19 (d, 9, J_{PH} = 7.93 Hz), 1.00 (d, 18, J_{PH} = 3.66 Hz), –0.11 (v br, 4, BH$_4$); ^{13}C NMR (ppm, C$_7$D$_8$, 90.56 MHz, {^{1}H}, –80 °C) δ 259.3 (br s, 1, CO) 248.8 (br s, 2, CO), 16.6 (t, 6, J_{PC} = 10.8 Hz, P(CH$_3$)$_3$), 16.2 (d, 3, J_{PC} = 25.3 Hz, P'-(CH$_3$)$_3$); ^{31}P NMR (ppm, C$_7$D$_8$, 36.2 MHz, {^{1}H}, –80 °C) δ –13.9 (t, 1, J_{PP} = 72.8 Hz), –29.2 (d, 2, J_{PP} = 72.8 Hz).
(19) Luetkens, M. L., Jr.; Santure, D. J.; Huffman, J. C.; Sattelberger, A. P. *J. Chem. Soc., Chem. Commun.*, in press.
(20) Anal. Calcd for [Ta(CO)$_3$(PMe$_3$)$_4$][Ta(CO)$_5$(PMe$_3$)]: C, 28.59; H, 4.69. Found: C, 27.85; H, 4.84. ^{1}H NMR (ppm, C$_4$D$_8$O, 360 MHz, 25 °C) δ 2.15 (d, 9, J_{PH} = 9.16 Hz), 2.01 (br t, 27, J_{PH} = 3.05 Hz), 1.81 (d, 9, J_{PH} = 5.80 Hz).
(21) **4** crystallizes in the monoclinic space group $P2_1/c$ with a = 9.404 (9) Å, b = 17.007 (7) Å, c = 22.494 (11) Å, β = 91.78 (3)°; V = 7191.5 Å^3, and ρ(calcd) = 1.785 g cm^{-3} for M_r = 966.37 and Z = 4. The structure was solved by Patterson and Fourier techniques and refined by full-matrix least squares. Final discrepancy indices were R_F = 0.044 and R_{wF} = 0.046 for those 4045 reflections with $F_o \geq 3\sigma(F_o)$. The limits of data collection were 6 $\leq 2\theta \leq 45°$ (Mo Kα).

(1) Nagasaki University.
(2) Kyushu University.
(3) Fendler, J. H. *Acc. Chem. Res.* **1980**, *13*, 7.
(4) Kunitake, T. *J. Macromol. Sci., Chem.* **1979**, *A13*, 587.
(5) Regen, S. L.; Czech, B.; Singh, A. *J. Am. Chem. Soc.* **1980**, *102*, 6638.
(6) Regen, S. L.; Shin, J.-S.; Yamaguchi, K. *J. Am. Chem. Soc.* **1984**, *106*, 2446.

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Communications to the Editor

tificial lipid (or the liquid-crystalline material) is embedded in a polymer matrix are applicable to practical permeation control, because a distinct change in thermal molecular motion occurs at the gel–liquid crystal phase-transition temperature (T_c) that causes a jump of water or gas permeability coefficients (P).[11,12] We here report on the thermocontrol of ion permeation through ternary composite membranes composed of polycarbonate (PC)/liquid crystal [N-(4-ethoxybenzylidene)-4'-butylaniline, EBBA]/amphiphilic crown ethers (**1**). When EBBA and **1** form discrete

$$CH_3CH_2O-\langle\rangle-CH=N-\langle\rangle-(CH_2)_3CH_3$$

EBBA

$$R-CO-N \quad NH^+-CH_2COO^-$$

1a. $R = CH_3(CH_2)_{10}-$
b. $R = (CH_3(CH_2)_{15}OCH_2)_2CHOCH_2-$

aggregates in the polymer matrix, permeation of K^+ ions can be suppressed completely below T_{KN} (phase transition temperature of EBBA) while it increases with temperature above T_{KN}. This is the first example for "complete" thermocontrol of ion permeation through the polymer composite membrane.

Preparation of **1a** was described previously.[13] **1b** was synthesized from O-(1,3-bis(hexadecyloxy)prop-2-yl)glycolyl chloride and N-(carboxymethyl)-1,10-diaza-4,7,13,16-tetraoxa-18-crown-6: mp 44–46 °C and identified by IR, NMR, TLC (one spot), and elemental analysis.[14] The composite membranes were prepared by evaporating solvent from the dichloromethane solutions, and the dispersion state was investigated by differential scanning calorimetry (DSC). The thickness of the membranes was 60 ± 2 μm. The PC/EBBA (40:60 wt/wt) binary composite membrane gave a DSC peak at 305 K, which is comparable with the crystal–nematic liquid crystal phase transition of EBBA ($T_{KN} = 304$ K). The peak was not affected by the addition of **1a** (2.9 mol % of EBBA) into the composite membrane. In contrast, the addition of **1b** (2.9 mol % of EBBA) gave a new peak, in addition to that of EBBA, at 313 K which is very close to a DSC peak of **1b** in water ($T_c = 317$ K)[15] or to that in the PC/**1b** binary composite membrane ($T_c = 317$ K). The finding supports that **1a** is homogeneously dispersed in the membrane phase, whereas **1b** exists as phase-separated aggregates not only in water but also in the composite membrane. We also prepared ternary composite membranes containing natural ionophores such as X-537A (lasalocid) or monensin instead of the crown ether. These membranes afforded only one DSC peak attributable to EBBA.

(7) Johnston, D. S.; Sanghera, S.; Pons, M.; Chapman, D. *Biochim. Biophys. Acta* **1980**, *602*, 57.

(8) Hub, H.; Hupfer, H.; Koch, H.; Ringsdorf, H. *Angew. Chem., Int. Ed. Engl.* **1980**, *19*, 938.

(9) (a) Kippenberger, D. J.; Rosenquist, K.; Odberg, L.; Tundo, P.; Fendler, J. *J. Am. Chem. Soc.* **1983**, *105*, 1129. (b) Tundo, P.; Kippenberger, D. J.; Klahn, P. L.; Prieto, N. E.; Jao, T.-C.; Fendler, J. H. *Ibid.* **1982**, *104*, 456. (c) Reed, W.; Guterman, L.; Tundo, P.; Fendler, J. H. *Ibid.* **1984**, *106*, 1897.

(10) Kunitake, T.; Nakashima, N. Takarabe, N.; Nagai, M.; Tsuge, A.; Yanagi, H. *J. Am. Chem. Soc.* **1981**, *103*, 5945.

(11) Kajiyama, T.; Nagata, Y.; Washizu, S.; Takayanagi, M. *J. Membr. Sci.* **1982**, *11*, 39.

(12) Washizu, S.; Terada, I.; Kajiyama, T.; Takayanagi, M. *Polym. J.* **1984**, *16*, 307.

(13) (a) Shinkai, S.; Kinda, H.; Sone, T.; Manabe, O. *J. Chem. Soc., Chem. Commun.* **1982**, 125. (b) Shinkai, S.; Kinda, H.; Araragi, Y.; Manabe, O. *Bull. Chem. Soc. Jpn.* **1983**, *56*, 559.

(14) Elemental analysis of **1b**. Found: C, 68.05; H, 11.38; N, 2.78%. Calcd for $C_{51}H_{100}N_2O_{10}$: C, 67.96; H, 11.18; N, 3.11%.

(15) **1b** gave a slightly turbid dispersion in water by sonication with a Branson 185 cell disruptor, but the sample solution stained for an electron micrograph formed a precipitate. Thus, we could not evaluate the aggregation morphology of **1b** in water. The appearance of the distinct DSC peak at 317 K indicates, however, that **1b** dispersed in water forms the oriented aggregates.

Figure 1. Temperature dependence of P_K^+: (●) PC/EBBA/**1a**, (○) PC/EBBA/**1b**.

Figure 2. Thermocontrol of K^+ permeation through the PC/EBBA/**1b** composite membrane.

Thermocontrol of K^+ permeation was estimated in a U-tube immersed in a thermostated water bath. The membrane area was 3.46 cm² and IN and OUT aqueous phases were 30.0 mL. The pK_a's for **1** were determined previously:[13] $pK_{a1} = 3.45$ for $>NH^+CH_2COOH \rightleftharpoons >NH^+CH_2COO^-$ and $pK_{a2} = 6.99$ for $>NH^+CH_2COO^- \rightleftharpoons >NCH_2COO^-$. The transport study with **1a** in a liquid membrane system established that $>NCH_2COO^-$ effectively extracts K^+ into the membrane phase with the aid of the anionic carboxylate cap while $> NH^+CH_2COO^-$ rapidly releases K^+ into the aqueous phase because of protonation of the ring nitrogen.[13] Thus, the pH's of IN (containing 0.30 M KSCN) and OUT aqueous phases were adjusted to 10.0 and 7.0 with K_2CO_3 (0.015 M)–HCl and Me_4NOH–H_3PO_4 (0.010 M), respectively. The concentration of K^+ permeated to the OUT aqueous phase was evaluated by atomic absorption spectroscopy. It was confirmed that K^+ does not permeate through the PC/ EBBA binary composite membrane.

Figure 1 shows plots of the permeability coefficient for K^+ (P_K^+) vs. transport temperature. Permeation of K^+ ion through the PC/EBBA/**1a** composite membrane was observed below and above T_{KN}, and the plot had a break point at around T_{KN}. In fact, the Arrhenius plot consisted of two straight lines intersecting at T_{KN}: $E_a = 6.2$ kcal mol^{-1} below T_{KN} and 8.9 kcal mol^{-1} above T_{KN}. The ternary composite membranes containing X-537A or monensin provided similar Arrhenius plots

consisting of two straight lines. Carrier-mediated K$^+$ permeation must thus be directly affected by the molecular motion of the liquid-crystal phase. In contrast, K$^+$ permeation through the PC/EBBA/1b composite membrane was "completely" suppressed below T_{KN} and increased with increasing temperature above T_{KN} (Figure 1): E_a = 15.3 kcal mol^{-1}. We conclude, therefore, that ion permeation below T_{KN} is largely governed by the dispersion state of the carriers.

In Figure 2, we demonstrate the reversible thermocontrol of K$^+$ permeation through the PC/EBBA/1b composite membrane. In response to a temperature change in the water bath (283 → 313 → 283 → 313 K), the rate of K$^+$ permeation showed an all-or-nothing change. The relatively slow response observed for a change from 313 to 283 K is attributed either to a leakage of K$^+$ dissolved in the membrane during the 313 K period or to an induction period for reorganization of the gel phase.

Detailed characterization of these and related composite membranes is now under intensive investigation. Of particular interest are (i) the rate of K$^+$ permeation may be sensitively controlled by a thermoswitch and (ii), since K$^+$ ion cannot permeate through the PC/EBBA/1b composite membrane below T_{KN}, it may be transported against its concentration gradient from the high-temperature cell ($T > T_{KN}$) to the low-temperature cell ($T < T_{KN}$). Statement (ii) would be regarded as a new class of thermodriven active transport. Further elaboration of the present concept might lead to the eventual development of a variety of thermocontrollable membranes.

Organomercurial Reagents for the Simultaneous Introduction of Mercury and a pH-Sensitive Reporter Functional Group into a Protein Containing No Thiol Group[1]

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We wish to report the synthesis, characterization, and demonstration of the utility of the organomercurial reagents 3-(acetoxymercurio)- and 3-(chloromercurio)-5-nitrosalicylaldehyde, which may be used to silmultaneously introduce a heavy-metal and a pH-sensitive reporter group[2] into a protein bearing no sulhydryl residue. Proteins thus modified may become amenable to X-ray structure analysis[3] and to examination of their quaternary interactions with other proteins bearing free sulhydral groups with which the mercurial-modified protein may react.

The synthesis of 3-(acetoxymercurio) and 3-(chloromercurio) derivatives of 5-nitrosalicylaldehyde was carried out by the scheme
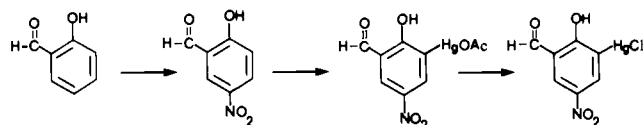
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§ Current address, Department of Medicinal Chemistry and Pharmacognosy, College of Pharmacy, University of Toledo, Toledo, OH 43606.
(1) (a) In partial fullfillment of the Ph.D. requirements of Eric Wohlfeil, Wayne State University. (b) Supported by National Institutes of Health, National Institute of Neurological Childhood Disorders and Stroke, NS-14491, and the National Cancer Institute, CA-27674.
(2) Hille, M. B.; Koshland D. E., Jr. *J. Am. Chem. Soc.* **1967**, *89*, 5945–5951.
(3) Edwards, B. F. P.; Evans, D. R.; Warren, S. G.; Monaco, H. L.; Landfear, S. M.; Eisele, G.; Crawford, J. L.; Wiley, D. C.; Lipscomb, W. N. *Proc. Natl. Acad. Sci. U.S.A.* **1974**, *71*, 4437–4441. These authors utilized previously prepared samples of the mercurial reagents described here to modify the essential cysteine of the catalytic subunit of E. coli aspartate transcarbamylase obtaining a valuable heavy-metal derivative for X-ray analysis. The present paper provides the first account of the synthesis and characterization of the reagents and their application to the modification of a protein not bearing a sulfhydral.

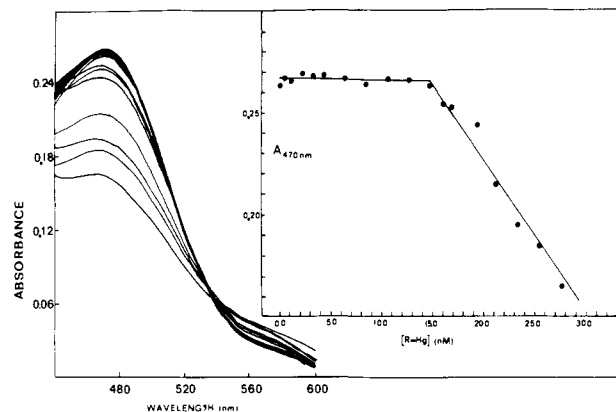**Figure 1.** Synthesis of 3-(choloromercurio)- and 3-(acetoxymercurio)-5-nitrosalicaldehyde.

Figure 2. Titration of 2-mercaptoethanol with 3-(acetoxymercurio)-5-nitrosalicaldehyde. Spectra correspond to mercurial concentrations (R-Hg) plotted in the insert as a function of observed absorbance at 470 nm (A_{470}).

Table I. pKs, Spectrophotometric Properties, and Melting Points of Mercurial Reagents, Model Reaction Products, and Neurotoxin Mercurial Derivatives

compounds	mp, °C	pK_a	max(base)	max(acid)	IP
5-nitrosalicyladehyde	126	5.5	360, 386	308	329
3-HgOAc derivative	310 dec	5.4	363, 395	315	332
3-HgOAc–EDTA Complex		7.8			
3-HgCl derivative	252 dec	5.4	365, 395	309	332
Benzyl alcohol derivative		6.9	414	316	366
(α-acetyllysyl)aminomethane derivative		5.7	400	310	345
neurotoxin A		4.8	400	325	352
neurotoxin B		5.1	400	325	348

in Figure 1. Salicylaldehyde was nitrated in nitric and acetic acid and pure 5-nitrosalicylaldehyde (mp 126–127 °C, uncorrected, cf. lit.[4]) obtained after two recrystallizations. The purified 5-nitrosalicylaldehyde (1.50 g, 9 mM) was heated in aqueous potassium hydroxide (26 mL, 0.03 M) at 70 °C while mercuric acetate (2.9 g, 9 mM) in aqueous acetic acid (25 mL, 0.08 M) was added over a 30-min period. During the addition a yellow-brown precipitate formed and was filtered subsequently from the hot solution, washed successively with acetic acid (0.08 M), water, methanol, and diethyl ether, and recrystallized from aqueous acetic acid (450 mL, 0.7 M). White needles were obtained (1.85 g, mp 310 °C dec, uncorrected). Anal. Calcd for C$_9$H$_7$HgNO$_6$: C, 25.37; H, 1.66; Hg, 47.12; N, 3.29. Found: C, 25.50; H, 1.73; Hg, 46.83; N, 3.36.

3-(Acetoxymercurio)-5-nitrosalicylaldehyde (1.85 g) could be converted to the 3-(chloromercurio) derivative by dissolution of the former in aqueous potassium hydroxide (900 mL, 0.03 M) and precipitation of the latter subsequent to dropwise neutrali-

(4) *Beilstein* **1925**, *8*, 56. An account of the preparation was also given later by: Harrison, G. C.; Diehl, H. *Iowa State J. Sci.* **1947**, *21*, 316–325. Cf.: Whitmore, F. C.; Middleton, E. B. *J. Am. Chem. Soc.* **1923**, *45*, 1330–1334.
(5) Klotz, I. M.; Carver, B. R. *Arch. Biochem. Biophys.* **1961**, *95*, 510–516.
(6) Karlsson, E. *Handb. Exp. Pharmacol.* **1979**, *52*, 159–212.
(7) Schmidt, D. E.; Westheimer, F. H. *Biochemistry*, **1971**, *10*, 1249–1253.
(8) Vinogradov, S. N.; Hudson, R. A.; Scott, R. M. *Biochim. Biophys. Acta* **1971**, *214*, 6–27.
(9) Karlsson, E.; Arnberg, H.; Eaker, D. *Eur. J. Biochem.* **1971**, *21*, 1–16.
(10) Walkinshaw, M. D.; Saenger, W.; Maelicke, A. *Proc. Natl. Acad. Sci. U.S.A.* **1980**, *77*, 2400–2404.