Supporting Information

Bis(dimethylamino)phosphorodiamidate – A reagent for the regioselective cyclophosphorylation of *cis*-diols enabling one-step access to high-value target cyclophosphates.

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General methods

Reagents and solvents were commercially available, of analytical grade and used without further purification. Commercially available substrates were purchased from Millipore Sigma, Oakwood, TCI Chemicals, Alfa Aesar, Fischer, Spectrum, Acros Organics and Combi Blocks. Specifically, Bis(dimethylamino)phosphorochloridate was purchased form Acros Organics and Dimethyltin dichloride was purchased form Spectrum. Reactions were monitored via ^{31}P NMR analysis on Bruker DPX- 400 (162 MHz for ^{31}P NMR) instrument. Additionally, reactions were monitored by TLC using silica gel coated plates with a fluorescence indicator (SiO_2-60, F-254) which were visualized a) under UV light and/or b) by dipping in phosphomolybdic acid solution or 20% H_2SO_4 in methanol followed by heating. Ion exchange chromatography was performed by using DEAE-A-25-sephadex ion exchange resin, 40-120 mesh, HCO_3^- form, 1.5 x 7.0 cm. Evaporation of solvents was carried out under reduced pressure at temperatures below 45 ºC or by lyophilization technique (Labconco lyophilizer). After ion exchange column chromatography, appropriate fractions were pooled, evaporated and dried at high vacuum for at least 12h to give the obtained products in high purity as ascertained by NMR techniques. NMR recorded at 298 K: Bruker DPX-400 (162 MHz for ^{31}P NMR) or AV-600 (600 MHz for ^{1}H and 151 MHz for ^{13}C) equipped with a 5mm DCH cryoprobe. Chemical shifts are reported relative to deuterated solvent or other internal standards. The following abbreviations were used to explain the multiplicities: s = singlet, d = doublet, t = triplet, q = quartet, m = multiplet. High–resolution mass spectra (HRMS) were recorded on a LCMS TOF mass spectrometer using electrospray ionization time-of-flight (ESI-TOF) reflectron experiments.

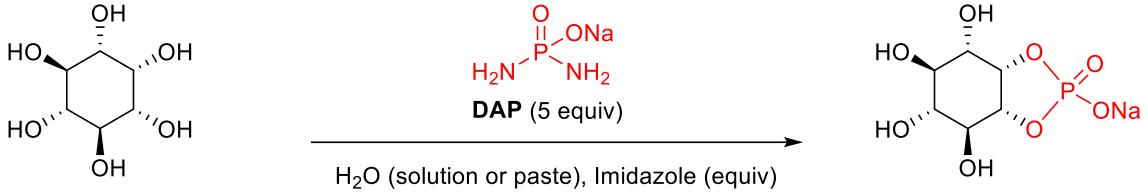
Initial attempts towards the phosphorylation of *myo*-inositol with DAP

Sodium diamidophosphate (DAP) was synthesized in a similar manner as published previously.[1]

Solution reaction: To a 1.5 mL eppendorf tube containing 0.1 M of the *myo*-inositol (1 equiv.) in H_2O, was added DAP (5 equiv.), imidazole (1 equiv.) and metal chloride (1 equiv. of magnesium chloride, if necessary). The pH of the reaction mixture was adjusted to 5.5 or 7.0 with (4 M) hydrochloric acid. The reactions were kept at room temperature and the pH was adjusted to 5.5 or 7.0 twice a day. The progress of the reaction was monitored by ^{1}H, ^{13}C and ^{31}P NMR spectroscopy (2 drops of D_2O were added to lock the sample for NMR). All the DAP was consumed in about 5 days (^{31}P NMR), but no phosphorylation of *myo*-inositol was observed (Supplementary Table 1).

Paste reaction: *myo*-Inositol (1 equiv.), DAP (5 equiv.), imidazole (5 equiv.) and about 2 drops of H_2O were placed in an eppendorf tube and the resulting mixture was ground using a glass rod to obtain a paste. The paste-reaction was kept at room temperature and ground (for 5 min every day). The progress of the reaction was monitored by taking a small portion of the paste-reaction mixture and dissolving it in 500 µL of D_2O. The pH of the solution was adjusted to 7 (from original pH of 8.5 and 9.5 - to ensure consistency in NMR chemical shifts) with hydrochloric acid (4 M) prior to the ^{1}H, ^{13}C and ^{31}P NMR spectroscopy measurement. All the DAP was consumed in 15 days, but only <10% phosphorylation of *myo*-inositol was observed with poor regioselectivity (Supplementary Table 1).

Supplementary table 1: Initial attempts towards the phosphorylation of *myo*-inositol with DAP[a,b]



1 *myo*-inositol

4 *myo*-inositol cyclophosphate (IcP)

entry	pH of the reaction	type of reaction	additive (equiv)	Imidazole (equiv)	yield of **4**
1	5.5	solution	--	1	ND
2	5.5	solution	$MgCl_2$ (1 equiv)	1	ND
3	7.0	solution	--	1	ND
4	7.0	solution	$MgCl_2$ (1 equiv)	1	ND
5[c]	unknown	paste	--	5	<10

[a]Reagents and conditions: **1** (0.1 mmol), **DAP** (5 equiv), additive (1 equiv), and imidazole (1-5 equiv) in solvent (1.0 mL for solution reaction and 20 uL for gel reaction) for 5 days. [b]Yields were calculated based on ^{1}H and ^{13}C NMR. [c]Reaction time was 15 days. ND = not detected. pH of reaction was adjusted by using dilute HCl.

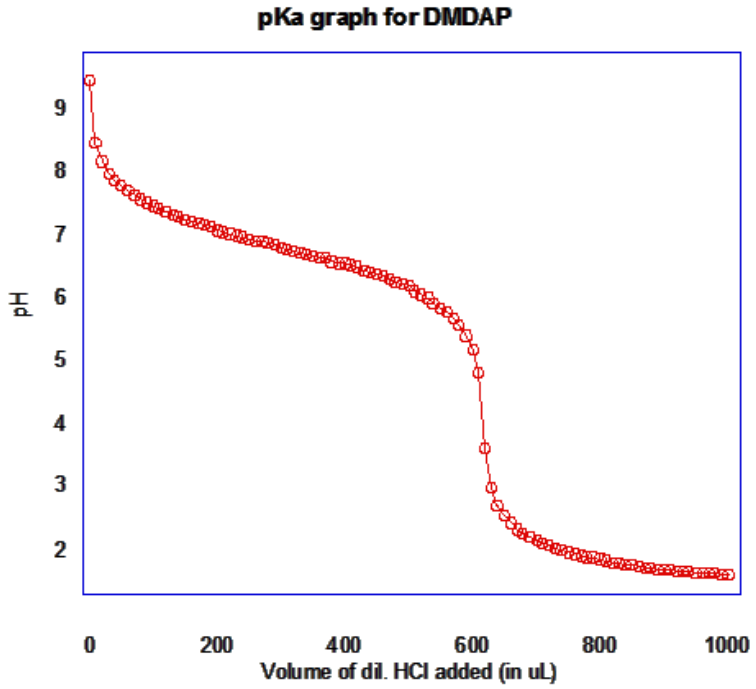
Synthesis of bis(dimethylamino)phosphorodiamidate sodium salt (BDMDAP)[2]

Bis(dimethylamino) phosphorochloridate (5 mmol) was added dropwise (over ~10 minutes) to a stirred solution of aqueous NaOH (2M solution, 5.2 mL) at 0 °C. After complete addition, the reaction mixture was stirred at room temperature until all the starting material was completely consumed (monitored by ^{31}P NMR), it took around 30 minutes. Final pH of the reaction mixture was adjusted to 9.0 (to avoid any hydrolysis of the product) by the addition of aqueous NaOH solution. Then the reaction mixture was concentrated under vacuum to afford almost quantitative bis(dimethylamino)phosphorodiamidate as product (852 mg, 98%) along with equimolar quantity of NaCl. Crude was dissolved in EtOH, filtered and the filtrate was concentrated under vacuum to afford the pure BDMDAP sodium salt as white powder. The pH of BDMDAP in aqueous solution (at 0.1 M) was 9.4.

^{1}H NMR (600 MHz, Deuterium Oxide) δ 2.42 (d, J = 10.2 Hz, 1H); ^{13}C NMR (151 MHz, Deuterium Oxide) δ 36.49 (d, J = 1.7 Hz); ^{31}P NMR (162 MHz, Deuterium Oxide) δ 19.34; HRMS (ESI/Q-TOF) m/z calculated for $C_4H_{13}N_2O_2P$ $[M-H]^-$ 151.0642, found 151.0637. Analysis calculated for $C_4H_{12}N_2NaO_2P.H_2O$: C, 25.01; H, 7.35; N, 14.58. Found: C, 24.88; H, 7.40; N, 14.55.

***p*Ka studies of bis(dimethylamino)phosphorodiamidate sodium salt (BDMDAP)**

BDMDAP (52.2 mg, 0.3 mmol) was dissolved in 2 mL of distilled H_2O in a 5 mL glass vial. pH meter was calibrated the with standard buffer solution at room temperature. After that rinsed the electrode with deionized water, gently wiped the excess water, and immersed the electrode in the BDMDAP solution. Allowed the reading to stabilize and recorded the pH. Then subsequent quantities of dil. HCl were added with an increment of 10 µl each time and pH was recorded at regular intervals. 100 readings were taken, and the titration curve was plotted as follows (Supplementary figure 1). Based upon this titration experiment, *p*Ka of BDMDAP was found to be 6.6.



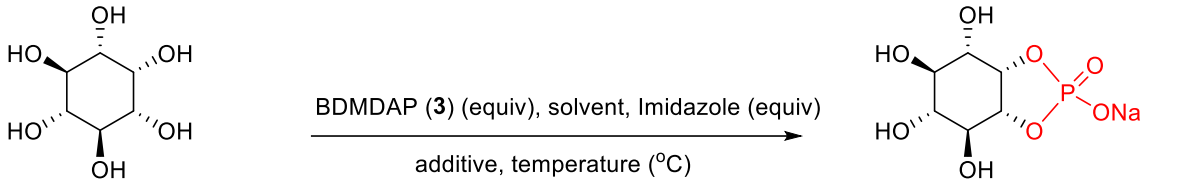
Supplementary figure 1: Titration curve of BDMDAP with dil. HCl to determine *p*Ka of bis(dimethylamino)phosphorodiamidate (BDMDAP).

Optimization of cyclophosphorylation of *myo*-inositol with BDMDAP

Procedure for paste reactions: In a 1.5 mL Eppendorf, *myo*-inositol (0.2 mmol), BDMDAP (0.4 mmol), additive (0.1-1 equiv) and imidazole (1-5 equiv) were dissolved in solvent of choice and then the reaction mixture was kept for a specified period at specified temperature. Progress of reaction was monitored by ^{31}P, ^{1}H and ^{13}C NMR.

Procedure for solution reactions: In a 10 ml RBF, *myo*-inositol (0.2 mmol), BDMDAP (0.2 mmol), and Sn(IV) catalyst (0.02 mmol) were dissolved/suspended in NMP and then the RBF was equipped with a reflux condenser and the reaction mixture was heated at 80 ºC in an oil bath for 12 h. Progress of reaction was monitored by ^{31}P, ^{1}H and ^{13}C NMR.

Supplementary table 2: Optimization table for cyclophosphorylation of *myo*-inositol with BDMDAP[a,b]



1
myo-inositol

4
myo-inositol cyclophosphate (IcP)

entry	solvent	type of reaction	BDMDAP (equiv)	additive (equiv)	temp. (°C)	imidazole (equiv)	yield of **4**
1[c]	H_2O	solution	5	-	rt	1	ND
2[d]	H_2O	solution	5	-	rt	1	ND
3	H_2O	paste	5	-	rt	5	ND
4	H_2O	paste	5	-	50	5	ND
5	NMP	paste	2	H_2SO_4 (0.1)	100	2	~10
6	DMF	paste	2	H_2SO_4 (0.1)	100	2	<5
7	DMSO	paste	2	H_2SO_4 (0.1)	100	2	<5
8	DMSO	paste	2	-	100	2	<5
9	NMP	paste	2	$ZnCl_2$ (1.0)	100	2	<5
10	NMP	paste	2	$MgCl_2$ (1.0)	100	2	~20
11	NMP	paste	2	Bu_2SnO (1.0)	100	2	~30
12	NMP	paste	3	Bu_2SnO (1.0)	100	2	~30
13	NMP	paste	3	Bu_2SnO (1.0)	100	1	~30
14	NMP	paste	2	Bu_2SnO (0.2)	100	1	40
15	NMP	solution	2	Bu_2SnO (0.2)	100	1	65
16	NMP	solution	2	Bu_2SnO (0.1)	100	1	65
17	NMP	solution	2	Bu_2SnO (0.1)	100	-	70
18	NMP	solution	2	Bu_2SnO (0.1)	80	-	75
19	NMP	solution	1	Bu_2SnO (0.1)	80	-	75
20	NMP	solution	1	Me_2SnCl_2 (0.1)	80	-	80
21[e]	NMP	solution	1	Me_2SnCl_2 (0.1)	80	-	80
22[f]	NMP	solution	1	Me_2SnCl_2 (0.1)	rt	-	ND

[a]Reagents and conditions: **1** (0.2 mmol), BDMDAP **3** (1-5 equiv), additive (0.1-1 equiv), and imidazole (1-5 equiv) in solvent (2.0 mL for solution reaction and 200 uL for paste reaction) for 12 h. [b]Yields of **4** were calculated based on ^1H and ^{13}C NMR. ND = not detected. [c]pH of the reaction mixture = 5.5. [d]pH of the reaction mixture = 7.0. [e]Reaction was performed under argon atmosphere. [f]Reaction time was 48 hrs.

General procedure for the phosphorylation reaction with BDMDAP

In a 10 ml RBF, *cis*-diol compound (0.2 mmol), BDMDAP (0.2 mmol, 1 equiv), and Me_2SnCl_2(0.02 mmol, 0.1 equiv) were dissolved/suspended in NMP (1 mL). Then the RBF was equipped with a reflux condenser and the reaction mixture was heated at 80 ºC in an oil bath for 8-12 h. Progress of the reaction was monitored by ^{31}P, ^{1}H and ^{13}C NMR. After completion, the reaction mixture was cooled to rt, dissolved in equal amount of H_2O (without removal of the solvent in vacuo) and loaded directly on the ion-exchange column (Sephadex A-25, bicarbonate form) and eluted with buffer ($NaHCO_3$ or triethylammonium bicarbonate) to afford the pure cyclophosphate-products as sodium salt/triethyl ammonium salt.

Representative example of a procedure for the phosphorylation of uridine (a detailed synthetic method example at 4 mmol scale)

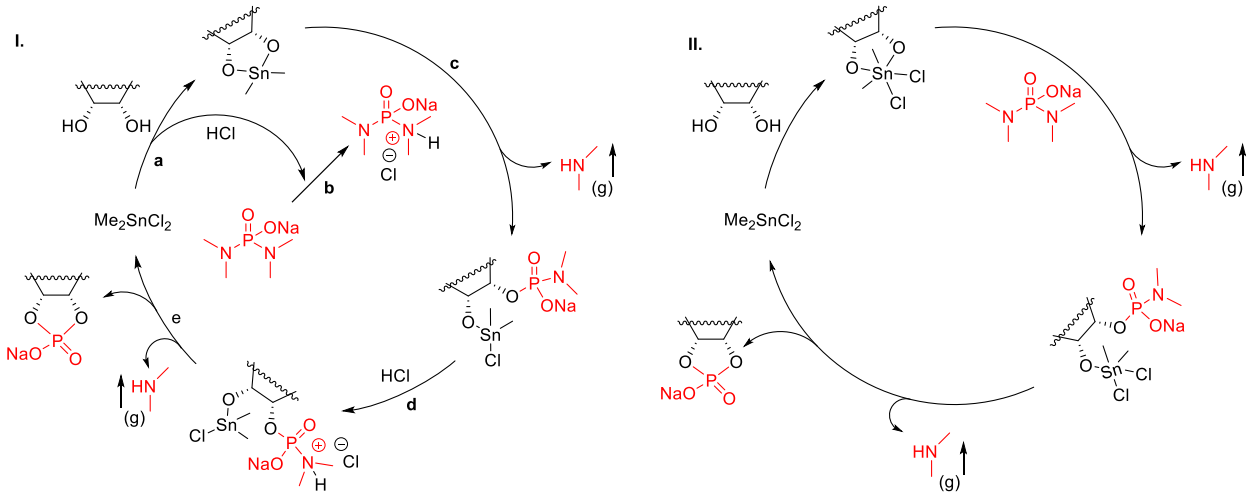
In a 50 ml RBF, uridine (1.0 g, 4.1 mmol), BDMDAP (0.713 g, 4.1 mmol, 1.0 equiv), and Me_2SnCl_2 (90.0 mg, 0.41 mmol, 0.1 equiv) were dissolved/suspended in NMP (8 mL). Then the RBF was equipped with a reflux condenser and the reaction mixture was heated at 80 ºC in an oil bath for 12 h. Progress of the reaction was monitored by ^{31}P, ^{1}H and ^{13}C NMR. After completion, the reaction mixture was cooled to rt, dissolved in equal amount of H_2O (without removal of the solvent in vacuo) and loaded directly on the ion-exchange column (Sephadex A-25, bicarbonate form, 3.0 x 8.0 cm). Then the ion-exchange column was first eluted with H_2O (300 mL) followed by elution with buffer (aq. triethylammonium bicarbonate, 0.05M – 0.5M $Et_3N.H_2CO_3$ in 0.05 M increments of 50 mL) to afford the pure fractions of the cyclophosphate-product (eluted in ~ 0.2M buffer) as triethyl ammonium salt. All the fractions containing the cyclophosphate-product were pooled and evaporation of the solvent under vacuum afforded pure uridine-2',3'-cyclophosphate **5** as triethyl ammonium salt (1.5 g, 90% yield).

Purification of the cyclophosphate products

The reaction mixture was dissolved in equal amount of water and subjected to ion-exchange chromatography (DEAE-A-25-sephadex, 40-120 mesh, HCO_3^- form, 1.5 x 5.0 cm, washed with 100 mL of water, followed by elution with 0.05M – 0.5M $NaHCO_3$ or $Et_3N.H_2CO_3$ in 0.05 M increments of 20 mL). The fractions containing the pure cyclophosphate product (monitored by ^{31}P NMR or UV) were combined, neutralized with Amberlite IR 120 H^+ (in case of $NaHCO_3$ buffer) and concentrated to dryness at 35 °C under vacuo or lyophilized to afford the pure cyclophosphate-products as sodium salt/triethyl ammonium salt.

Proposed mechanism for the cyclophosphorylation reaction with BDMDAP

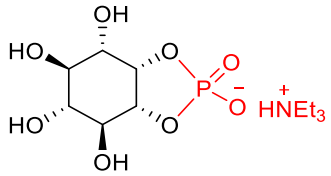
The cyclophosphorylation of the *cis*-diols could proceed via two possible mechanisms as shown in Scheme 1. The first (Scheme 1.I) is a step-wise process: (a) The Me_2SnCl_2 forms a stannylene-acetal[3] with the *cis*-diol releasing two molecules of HCl; (b) The acid thus released protonates one of the dimethylamine moieties on BDMDAP (pKa ≈ 6.6) and activates the BDMDAP for (c) attack by the stannylene-acetal oxygens. This step is proposed to proceed stepwise with the (c) first phosphorylation one of the two *cis*-diol oxygens, followed by (d) the protonation of the next dimethylamino moiety and (e) subsequent attack by the next stannylene acetal oxygen to form the cyclphosphate. Under the reaction conditions dimethylamine is released as a gas which regenerates the Me_2SnCl_2 cataylst for the next round of stannylene-acetal formation. While we have not detected any of the proposed intermediates by NMR, this hypothesis rests on previous proposals of stannylene acetal formation[3] and the cyclophosphorylation by the parent diamidophosphate (DAP) mediated by protonation chemistries. [1] Alternatively, as shown in Scheme 1.II, the reaction could proceed via the dichlorostannolane complex (a possibility that has been invoked),[3] which reacts stepwise with BDMDAP to form the cylophosphate product while regenerating the dimethyltin dichloride and forming dimethyl amine (which escapes as a gas). At present we do not have any data that would strongly rule out I or II and further studies are needed that would provide evidences for or against them.



Supplementary Scheme 1: The proposed mechanistic pathways for the cyclophosphorylation of *cis*-diol with BDMDAP catalyzed by Me_2SnCl_2.

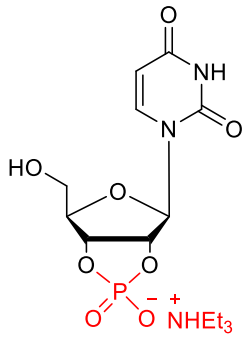
Compound Characterization

myo-Inositol-1,2-cyclophosphate (4)



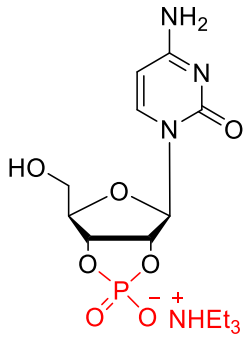
Sephadex column chromatography ($Et_3N.H_2CO_3$, 0.2M as eluent) afforded the cyclophosphate product **4** as triethylammonium salt (137 mg, 80% from 90 mg of **1**). ^{1}H NMR (600 MHz, Deuterium Oxide) δ 4.64 (t, *J* = 4.2 Hz, 1H), 4.24 (ddd, *J* = 20.1, 8.4, 4.7 Hz, 1H), 3.75 (dd, *J* = 10.1, 8.5 Hz, 1H), 3.67 (ddd, *J* = 10.1, 3.8, 2.1 Hz, 1H), 3.56 (t, *J* = 9.9 Hz, 1H), 3.21 (t, *J* = 10.0 Hz, 1H), 3.13 (q, *J* = 7.3 Hz, 12H), 1.20 (t, *J* = 7.3 Hz, 18H); ^{13}C NMR (151 MHz, Deuterium Oxide) δ 79.23, 76.65 (d, *J* = 2.7 Hz), 73.29, 71.61, 70.94, 69.29 (d, *J* = 10.1 Hz), 46.20, 7.76; ^{31}P NMR (162 MHz, Deuterium Oxide) δ 16.61; HRMS (ESI/Q-TOF) m/z calculated for $C_6H_{11}O_8P$ $[M-H]^-$ 241.0119, found 241.0126.

Uridine-2',3'-cyclophosphate (5)



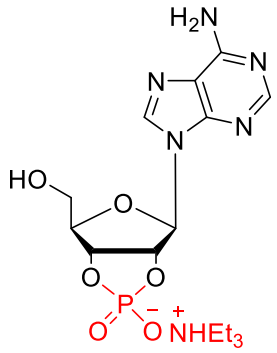
Sephadex column chromatography ($Et_3N.H_2CO_3$, 0.2M as eluent) afforded the cyclophosphate product **5** as triethylammonium salt (187 mg, 92% from 122 mg of uridine). ^{1}H NMR (600 MHz, Deuterium Oxide) δ 7.47 (d, *J* = 7.6 Hz, 1H), 5.76 (d, *J* = 2.9 Hz, 1H), 5.69 (d, *J* = 7.6 Hz, 1H), 5.06 (td, *J* = 6.6, 3.0 Hz, 1H), 4.85 (dt, *J* = 12.3, 6.3 Hz, 1H), 4.18 (q, *J* = 5.5 Hz, 1H), 3.82 (dd, *J* = 12.3, 3.7 Hz, 1H), 3.75 (dd, *J* = 12.3, 5.6 Hz, 1H), 3.04 (q, *J* = 7.3 Hz, 12H), 1.16 (t, *J* = 7.4 Hz, 18H); ^{13}C NMR (151 MHz, Deuterium Oxide) δ 175.61, 157.58, 142.28, 102.14, 92.87 (d, *J* = 6.2 Hz), 84.19 (d, *J* = 1.8 Hz), 80.20 (d, *J* = 2.1 Hz), 76.74, 60.62, 46.05, 7.90; ^{31}P NMR (162 MHz, Deuterium Oxide) δ 21.1; ESI-MS m/z calculated for $C_9H_{11}N_2O_8P$ $[M-H]^-$ 305, found 305.

Cytidine-2',3'-cyclophosphate (6)



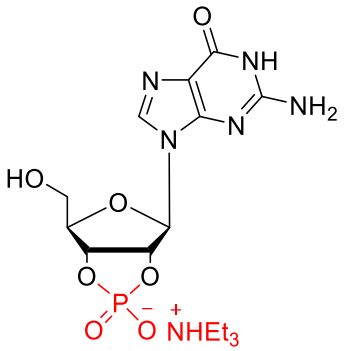
Sephadex column chromatography ($Et_3N.H_2CO_3$, 0.2M as eluent) afforded the cyclophosphate product **6** as triethylammonium salt (185 mg, 91% from 122 mg of cytidine). ^{1}H NMR (600 MHz, Deuterium Oxide) δ 7.62 (d, *J* = 7.5 Hz, 1H), 5.96 (d, *J* = 7.5 Hz, 1H), 5.78 (d, *J* = 2.7 Hz, 1H), 5.06 (td, *J* = 6.6, 2.7 Hz, 1H), 4.86 (dt, *J* = 12.2, 6.2 Hz, 1H), 4.41 – 4.04 (m, 1H), 3.84 (dd, *J* = 12.3, 3.6 Hz, 1H), 3.76 (dd, *J* = 12.3, 5.7 Hz, 1H), 3.13 (q, *J* = 7.3 Hz, 24H), 1.21 (t, *J* = 7.4 Hz, 36H); ^{13}C NMR (151 MHz, Deuterium Oxide) δ 165.75, 156.15, 143.43, 95.61, 93.26 (d, *J* = 6.2 Hz), 84.65, 80.44 (d, *J* = 2.2 Hz), 76.82, 60.63, 46.23, 7.82; ^{31}P NMR (162 MHz, Deuterium Oxide) δ 21.05; ESI-MS m/z calculated for $C_9H_{12}N_3O_7P$ $[M-H]^-$ 304, found 304.

Adenosine-2',3'-cyclophosphate (7):



Sephadex column chromatography ($Et_3N.H_2CO_3$, 0.2M as eluent) afforded the cyclophosphate product **7** as triethylammonium salt (193 mg, 90% from 134 mg of adenosine). ^{1}H NMR (600 MHz, Deuterium Oxide) δ 8.22 (s, 1H), 8.12 (s, 1H), 6.19 (d, *J* = 4.3 Hz, 1H), 5.36 (ddd, *J* = 10.8, 6.8, 4.4 Hz, 1H), 5.06 (td, *J* = 7.4, 4.2 Hz, 1H), 4.41 (q, *J* = 3.7 Hz, 1H), 3.85 (dd, *J* = 12.7, 3.1 Hz, 1H), 3.80 (dd, *J* = 12.7, 4.4 Hz, 1H), 3.12 (q, *J* = 7.3 Hz, 12H), 1.20 (t, *J* = 7.3 Hz, 18H); ^{13}C NMR (151 MHz, Deuterium Oxide) δ 155.12, 152.23, 147.90, 140.25, 118.49, 88.95 (d, *J* = 3.7 Hz), 84.80 (d, *J* = 4.1 Hz), 79.82 (d, *J* = 1.6 Hz), 77.06, 60.60, 46.19, 7.74; ^{31}P NMR (162 MHz, Deuterium Oxide) δ 20.61; ESI-MS m/z calculated for $C_{10}H_{12}N_5O_6P$ $[M-H]^-$ 328, found 328.

Guanosine-2',3'-cyclophosphate (8)

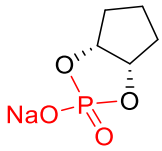


Sephadex column chromatography ($Et_3N.H_2CO_3$, 0.2M as eluent) afforded the cyclophosphate product **8** as triethylammonium salt (196 mg, 88% from 142 mg of guanosine). ^{1}H NMR (600 MHz, Deuterium Oxide) δ 7.88 (s, 1H), 6.06 (d, J = 3.7 Hz, 1H), 5.35 (ddd, J = 8.8, 6.8, 3.7 Hz, 1H), 5.07 (ddd, J = 9.6, 6.8, 4.6 Hz, 1H), 4.34 (q, J = 4.4 Hz, 1H), 3.83 (dd, J = 12.5, 3.6 Hz, 1H), 3.77 (dd, J = 12.5, 4.9 Hz, 1H), 3.12 (q, J = 7.3 Hz, 9H), 1.20 (t, J = 7.3 Hz, 14H); ^{13}C NMR (151 MHz, Deuterium Oxide) δ 158.70, 153.52, 150.75, 137.73, 116.07, 88.45 (d, J = 4.7 Hz), 84.74 (d, J = 3.4 Hz), 79.96 (d, J = 2.0 Hz), 77.04, 60.54, 46.18, 7.73; ^{31}P NMR (162 MHz, Deuterium Oxide) δ 20.67; ESI-MS m/z calculated for $C_{10}H_{12}N_5O_7P$ $[M-H]^-$ 344, found 344.

1,4-Anhydroerythritol-2,3-cyclophosphate (9)

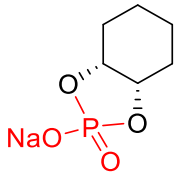
Sephadex column chromatography ($NaHCO_3$, 0.2M as eluent) afforded the cyclophosphate product **9** as sodium salt (90 mg, 95% from 52 mg of 1,4-anhydroerythritol). ^{1}H NMR (600 MHz, Deuterium Oxide) δ 5.10 – 4.87 (m, 2H), 4.02 (d, J = 11.4 Hz, 2H), 3.57 (d, J = 11.1 Hz, 2H); ^{13}C NMR (151 MHz, Deuterium Oxide) δ 78.54, 73.10 (d, J = 3.4 Hz); ^{31}P NMR (162 MHz, Deuterium Oxide) δ 21.43; HRMS (ESI/Q-TOF) m/z calculated for $C_4H_7O_5P$ $[M-H]^-$ 164.9958, found 164.9963.

***cis*-Cyclopentane-1,2-diol cyclophosphate (10)**



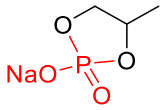
Sephadex column chromatography ($NaHCO_3$, 0.2M as eluent) afforded the cyclophosphate product **10** as sodium salt (86 mg, 93% from 51 mg of *cis*-Cyclopentane-1,2-diol). ^{1}H NMR (600 MHz, Deuterium Oxide) δ 4.84 – 4.79 (m, 2H), 1.86 – 1.80 (m, 2H), 1.80 – 1.71 (m, 1H), 1.70 – 1.62 (m, 2H), 1.61 – 1.54 (m, 1H); ^{13}C NMR (151 MHz, Deuterium Oxide) δ 82.70 (d, J = 1.5 Hz), 32.78 (d, J = 4.2 Hz), 21.30; ^{31}P NMR (162 MHz, Deuterium Oxide) δ 20.09; HRMS (ESI/Q-TOF) m/z calculated for $C_5H_9O_4P$ $[M-H]^-$ 163.0166, found 163.0172.

***cis*-Cyclohexane-1,2-diol cyclophosphate (11)**



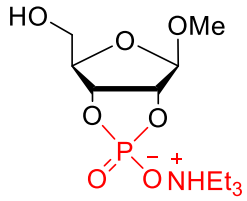
Sephadex column chromatography ($NaHCO_3$, 0.2M as eluent) afforded the cyclophosphate product **11** as sodium salt (95 mg, 95% from 58 mg of *cis*-Cyclohexane-1,2-diol). ^{1}H NMR (600 MHz, Deuterium Oxide) δ 4.43 (dt, J = 8.9, 4.2 Hz, 2H), 1.87 – 1.68 (m, 4H), 1.47 (dq, J = 13.7, 8.7 Hz, 2H), 1.33 – 1.20 (m, 2H); ^{13}C NMR (151 MHz, Deuterium Oxide) δ 76.43, 27.73 (d, J = 6.0 Hz), 19.76; ^{31}P NMR (162 MHz, Deuterium Oxide) δ 16.85; HRMS (ESI/Q-TOF) m/z calculated for $C_6H_{11}O_4P$ $[M-H]^-$ 177.0322, found 177.0330.

Propane-1,2-diol cyclophosphate (12)



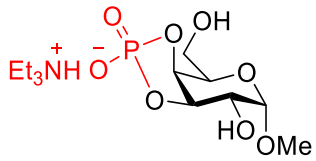
Sephadex column chromatography ($NaHCO_3$, 0.2M as eluent) afforded the cyclophosphate product **12** as sodium salt (77 mg, 96% from 38 mg of propane-1,2-diol). ^{1}H NMR (600 MHz, Deuterium Oxide) δ 4.58 – 4.52 (m, 1H), 4.24 (ddd, J = 15.1, 9.1, 5.6 Hz, 1H), 3.80 – 3.72 (m, 1H), 1.28 (d, J = 6.2 Hz, 3H); ^{13}C NMR (151 MHz, Deuterium Oxide) δ 73.76 (d, J = 2.1 Hz), 70.56 (d, J = 1.1 Hz), 17.73 (d, J = 6.5 Hz); ^{31}P NMR (162 MHz, Deuterium Oxide) δ 18.59; ESI-MS m/z calculated for $C_3H_7O_4P$ $[M-H]^-$ 137, found 137.

Methyl ribopyranoside-2,3-cyclophosphate (13)



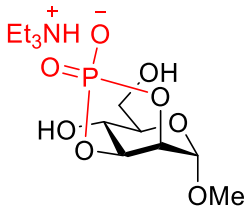
Sephadex column chromatography ($Et_3N.H_2CO_3$, 0.2M as eluent) afforded the cyclophosphate product **13** as triethylammonium salt (147 mg, 90% from 82 mg of methyl ribofuranoside). ^{1}H NMR (600 MHz, Deuterium Oxide) δ 5.10 (s, 1H), 4.82 (ddd, *J* = 10.5, 6.1, 1.9 Hz, 1H), 4.73 (d, *J* = 6.9 Hz, 1H, merged with H_2O peak), 4.36 – 4.23 (m, 1H), 3.59 (qd, *J* = 11.9, 6.5 Hz, 2H), 3.34 (s, 3H), 3.13 (q, *J* = 7.3 Hz, 12H), 1.21 (t, *J* = 7.3 Hz, 18H); ^{13}C NMR (151 MHz, Deuterium Oxide) δ 107.87 (d, *J* = 5.8 Hz), 85.99 (d, *J* = 2.5 Hz), 81.69 (d, *J* = 1.3 Hz), 78.61, 61.81, 54.62, 46.20, 7.76; ^{31}P NMR (162 MHz, Deuterium Oxide) δ 20.66; HRMS (ESI/Q-TOF) m/z calculated for $C_6H_{11}O_7P$ $[M-H]^-$ 225.0170, found 225.0178.

Methyl galactopyranoside-3,4-cyclophosphate (14)



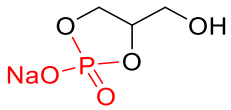
Sephadex column chromatography ($Et_3N.H_2CO_3$, 0.2M as eluent) afforded the cyclophosphate product **14** as triethylammonium salt (61 mg, 85% from 39 mg of methyl galactopyranoside). ^{1}H NMR (600 MHz, Deuterium Oxide) δ 4.79 (d, *J* = 3.8 Hz, 1H), 4.56 (dd, *J* = 5.1, 1.8 Hz, 1H), 4.39 (ddd, *J* = 19.3, 8.7, 5.2 Hz, 1H), 4.00 (ddt, *J* = 6.5, 4.2, 2.2 Hz, 1H), 3.93 (dd, *J* = 8.7, 3.8 Hz, 1H), 3.82 – 3.70 (m, 2H), 3.35 (s, 3H), 3.13 (q, *J* = 7.3 Hz, 15H), 1.20 (t, *J* = 7.3 Hz, 24H); ^{13}C NMR (151 MHz, Deuterium Oxide) δ 98.47, 77.12, 73.97 (d, *J* = 2.6 Hz), 68.37, 67.30 (d, *J* = 9.2 Hz), 60.14, 54.82, 46.20, 7.75; ^{31}P NMR (162 MHz, Deuterium Oxide) δ 16.74; HRMS (ESI/Q-TOF) m/z calculated for $C_7H_{13}O_8P$ $[M+H]^+$ 257.0421, found 257.0424.

Methyl mannopyranoside-3,4-cyclophosphate (15)



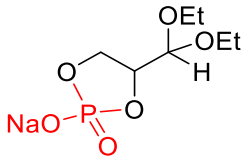
Sephadex column chromatography ($Et_3N.H_2CO_3$, 0.2M as eluent) afforded the cyclophosphate product **15** as triethylammonium salt (62 mg, 85% from 39 mg of methyl mannopyranoside). ^{1}H NMR (600 MHz, Deuterium Oxide) δ 4.95 (s, 1H), 4.43 (d, *J* = 5.3 Hz, 1H), 4.31 (ddd, *J* = 19.3, 8.2, 5.3 Hz, 1H), 3.85 (dd, *J* = 12.4, 2.2 Hz, 1H), 3.78 (dd, *J* = 10.2, 8.4 Hz, 1H), 3.69 (dd, *J* = 12.3, 6.2 Hz, 1H), 3.59 (ddd, *J* = 10.1, 6.2, 2.2 Hz, 1H), 3.35 (s, 3H), 3.13 (q, *J* = 7.3 Hz, 18H), 1.21 (t, *J* = 7.3 Hz, 27H); ^{13}C NMR (151 MHz, Deuterium Oxide) δ 97.03 (d, *J* = 14.4 Hz), 78.48, 74.58 (d, *J* = 3.1 Hz), 69.27, 67.00, 60.07, 54.29, 46.20, 7.76; ^{31}P NMR (162 MHz, Deuterium Oxide) δ 15.89; HRMS (ESI/Q-TOF) m/z calculated for $C_7H_{13}O_8P$ $[M+H]^+$ 257.0421, found 257.0419.

Glycerol-1,2-cyclophosphate (16)



Sephadex column chromatography ($NaHCO_3$, 0.2M as eluent) afforded the cyclophosphate product **16** as sodium salt (66 mg, 75% from 46 mg of glycerol). ^{1}H NMR (600 MHz, Deuterium Oxide) δ 4.49 (pd, *J* = 6.4, 3.9 Hz, 1H), 4.25 (ddd, *J* = 12.4, 9.3, 6.4 Hz, 1H), 3.95 (td, *J* = 9.1, 7.3 Hz, 1H), 3.68 (dd, *J* = 12.5, 3.8 Hz, 1H), 3.63 (dd, *J* = 12.5, 6.3 Hz, 1H); ^{13}C NMR (151 MHz, Deuterium Oxide) δ 76.33 (d, *J* = 1.6 Hz), 65.35, 61.48 (d, *J* = 5.6 Hz); ^{31}P NMR (162 MHz, Deuterium Oxide) δ 18.86; ESI-MS m/z calculated for $C_3H_7O_5P$ $[M-H]^-$ 153, found 153.

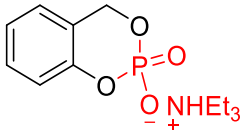
Glyceraldehyde diethyl acetal-2,3-cyclophosphate (17)



Sephadex column chromatography ($NaHCO_3$, 0.2M as eluent) afforded the cyclophosphate product **17** as sodium salt (93 mg, 75% from 46 mg of glyceraldehyde diethyl acetal). ^{1}H NMR (600 MHz, Deuterium Oxide) δ 4.65 (d, *J* = 6.7 Hz, 1H, merged with H_2O peak), 4.32 (p, *J* = 6.6 Hz, 1H), 4.25 (ddd, *J* = 12.0, 9.5, 6.5 Hz, 1H), 4.05 (td, *J* = 9.5, 6.6 Hz, 1H), 3.83 – 3.73 (m, 2H),

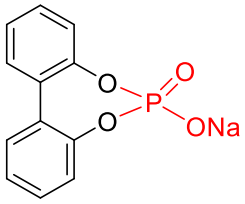
3.67 (ddq, J = 21.3, 9.6, 7.1 Hz, 2H), 1.15 (dt, J = 16.9, 7.1 Hz, 6H); ^{13}C NMR (151 MHz, Deuterium Oxide) δ 101.49 (d, J = 6.7 Hz), 74.60 (d, J = 2.2 Hz), 64.92, 64.68, 64.00, 13.89, 13.88; ^{31}P NMR (162 MHz, Deuterium Oxide) δ 18.74; HRMS (ESI/Q-TOF) m/z calculated for $C_7H_{15}O_6P$ $[M+Na]^+$ 249.0498, found 249.0502.

Saligenin cyclophosphate (18)



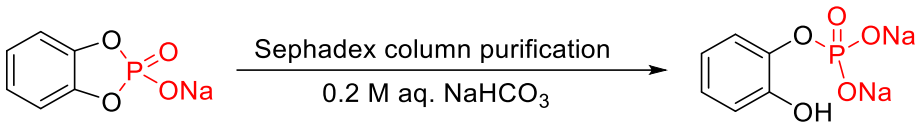
Sephadex column chromatography ($Et_3N.H_2CO_3$, 0.2M as eluent) afforded the cyclophosphate product **18** as triethylammonium salt (135 mg, 94% from 62 mg of saligenin). ^{1}H NMR (600 MHz, Deuterium Oxide) δ 7.25 (t, J = 7.7 Hz, 1H), 7.10 (d, J = 7.5 Hz, 1H), 7.05 (t, J = 7.5 Hz, 1H), 6.94 (d, J = 8.2 Hz, 1H), 5.19 (d, J = 12.7 Hz, 2H), 3.10 (q, J = 7.3 Hz, 12H), 1.19 (t, J = 7.4 Hz, 18H); ^{13}C NMR (151 MHz, Deuterium Oxide) δ 150.28 (d, J = 6.0 Hz), 128.69, 125.10, 122.65, 121.20 (d, J = 9.7 Hz), 117.86 (d, J = 8.2 Hz), 66.56 (d, J = 5.8 Hz), 46.20, 7.77; ^{31}P NMR (162 MHz, Deuterium Oxide) δ -5.33; HRMS (ESI/Q-TOF) m/z calculated for $C_7H_7O_4P$ $[M-H]^-$ 185.0009, found 185.0014.

2,2'-Biphenol cyclophosphate (19)



Sephadex column chromatography ($NaHCO_3$, 0.2M as eluent) afforded the cyclophosphate product **19** as sodium salt (115 mg, 85% from 93 mg of 2,2'-biphenol). ^{1}H NMR (600 MHz, Deuterium Oxide) δ 7.56 (dd, J = 7.7, 1.4 Hz, 2H), 7.44 (t, J = 7.7 Hz, 2H), 7.34 (t, J = 7.6 Hz, 2H), 7.23 (d, J = 8.1 Hz, 2H); ^{13}C NMR (151 MHz, Deuterium Oxide) δ 148.13 (d, J = 8.8 Hz), 129.56, 129.21, 128.42 (d, J = 1.1 Hz), 125.39 (d, J = 1.2 Hz), 120.77 (d, J = 3.6 Hz); ^{31}P NMR (162 MHz, Deuterium Oxide) δ 6.54; HRMS (ESI/Q-TOF) m/z calculated for $C_{12}H_9O_4P$ $[M-H]^-$ 247.0166, found 247.0180.

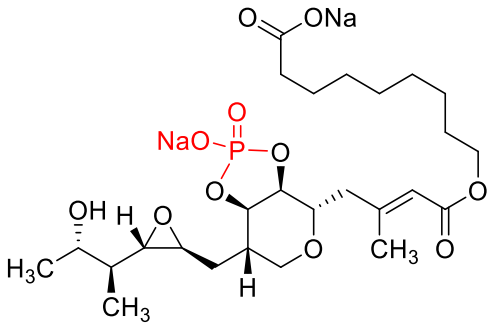
Catechol monophosphate[4] 20a (from catechol cyclophosphate 20)



Catechol-cP (**20**) Catechol monophosphate (**20a**)

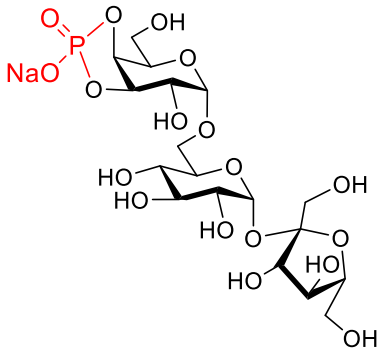
Sephadex column chromatography ($NaHCO_3$, 0.2M as eluent) afforded the catechol monophosphate **20a** as disodium salt (90 mg, 77% from 55 mg of catechol). ^{1}H NMR (600 MHz, Deuterium Oxide) δ 7.06 (d, *J* = 8.0 Hz, 1H), 6.92 (t, *J* = 7.4 Hz, 1H), 6.83 (dd, *J* = 8.0, 1.3 Hz, 1H), 6.78 (td, *J* = 7.7, 1.4 Hz, 1H); ^{13}C NMR (151 MHz, Deuterium Oxide) δ 147.70, 141.34 (d, *J* = 6.3 Hz), 123.67, 121.66 (d, *J* = 3.1 Hz), 120.06, 117.10.; ^{31}P NMR (162 MHz, Deuterium Oxide) δ 3.15; ESI-MS m/z calculated for $C_6H_7O_5P$ $[M-H]^-$ 189, found 189.

Mupirocin sodium cyclophosphate (21)



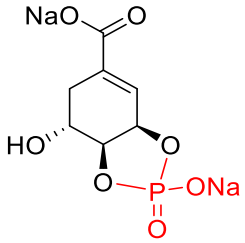
Sephadex column chromatography ($NaHCO_3$, 0.2-0.4M as eluent) afforded the cyclophosphate product **21** as sodium salt (24 mg, 80% from 25 mg of mupirocin lithium). ^{1}H NMR (600 MHz, Deuterium Oxide) δ 5.69 (s, 1H), 4.48 (s, 1H), 4.13 (ddd, *J* = 16.3, 8.4, 4.6 Hz, 1H), 4.02 (d, *J* = 6.5 Hz, 2H), 3.86 (td, *J* = 9.3, 3.3 Hz, 1H), 3.79 – 3.70 (m, 2H), 3.59 (dd, *J* = 12.2, 2.5 Hz, 1H), 2.97 – 2.95 (m, 1H), 2.80 (dd, *J* = 8.0, 2.4 Hz, 1H), 2.48 (d, *J* = 11.7 Hz, 1H), 2.30 (dd, *J* = 14.9, 9.7 Hz, 1H), 2.24 – 2.20 (m, 1H), 2.09 – 1.99 (m, 5H), 1.74 – 1.66 (m, 1H), 1.58 – 1.52 (m, 3H), 1.43 – 1.34 (m, 3H), 1.27 – 1.13 (m, 8H), 1.09 (d, *J* = 6.5 Hz, 3H), 0.83 (d, *J* = 7.1 Hz, 3H); ^{13}C NMR (151 MHz, Deuterium Oxide) δ 183.78, 168.38, 156.39, 117.11, 75.77, 75.76, 74.26, 73.76, 69.27, 64.57, 60.97, 55.90, 41.80, 41.39, 37.16, 35.25, 30.60, 28.14, 27.88, 27.69, 27.31, 25.36, 24.66, 18.42, 17.80, 10.63; ^{31}P NMR (162 MHz, Deuterium Oxide) δ 16.01; HRMS (ESI/Q-TOF) m/z calculated for $C_{26}H_{42}NaO_{11}P$ $[M+Na]^+$ 607.2255, found 607.2257.

Raffinose cyclophosphate (22)



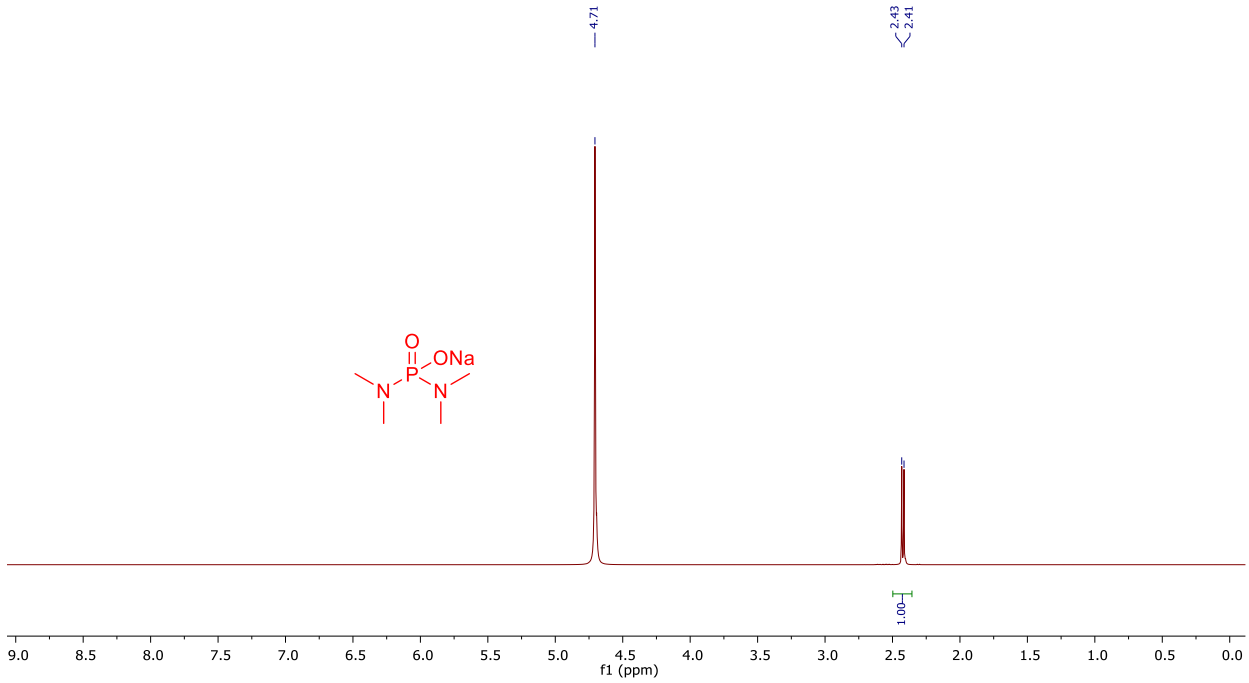
Sephadex column chromatography ($NaHCO_3$, 0.2-0.3M as eluent) afforded the cyclophosphate product **22** as sodium salt (53 mg, 90% from 50 mg of raffinose). ^{1}H NMR (600 MHz, Deuterium Oxide) δ 5.36 (d, *J* = 3.9 Hz, 1H), 4.97 (d, *J* = 3.7 Hz, 1H), 4.61 (dd, *J* = 5.2, 1.9 Hz, 1H), 4.49 (ddd, *J* = 19.2, 8.8, 5.2 Hz, 1H), 4.16 (d, *J* = 8.8 Hz, 1H), 4.07 (td, *J* = 4.6, 2.2 Hz, 1H), 3.97 (ddt, *J* = 12.7, 9.0, 6.1 Hz, 4H), 3.83 (td, *J* = 8.7, 8.1, 3.1 Hz, 1H), 3.81 – 3.77 (m, 1H), 3.77 – 3.74 (m, 1H), 3.73 – 3.67 (m, 3H), 3.66 – 3.60 (m, 3H), 3.51 (dd, *J* = 10.0, 3.9 Hz, 1H), 3.46 (t, *J* = 9.6 Hz, 1H); ^{13}C NMR (151 MHz, Deuterium Oxide) δ 103.33, 97.58, 91.67, 80.88, 77.03, 75.92, 74.04 (d, *J* = 2.4 Hz), 73.55, 72.18, 70.80, 70.46, 68.86, 68.63, 67.62 (d, *J* = 9.2 Hz), 65.79, 61.98, 60.94, 60.11; ^{31}P NMR (162 MHz, Deuterium Oxide) δ 16.55; HRMS (ESI/Q-TOF) m/z calculated for $C_{18}H_{31}O_{18}P$ $[M+Na]^+$ 589.1140, found 589.1155.

Sodium shikimate-3,4-cyclophosphate (23)

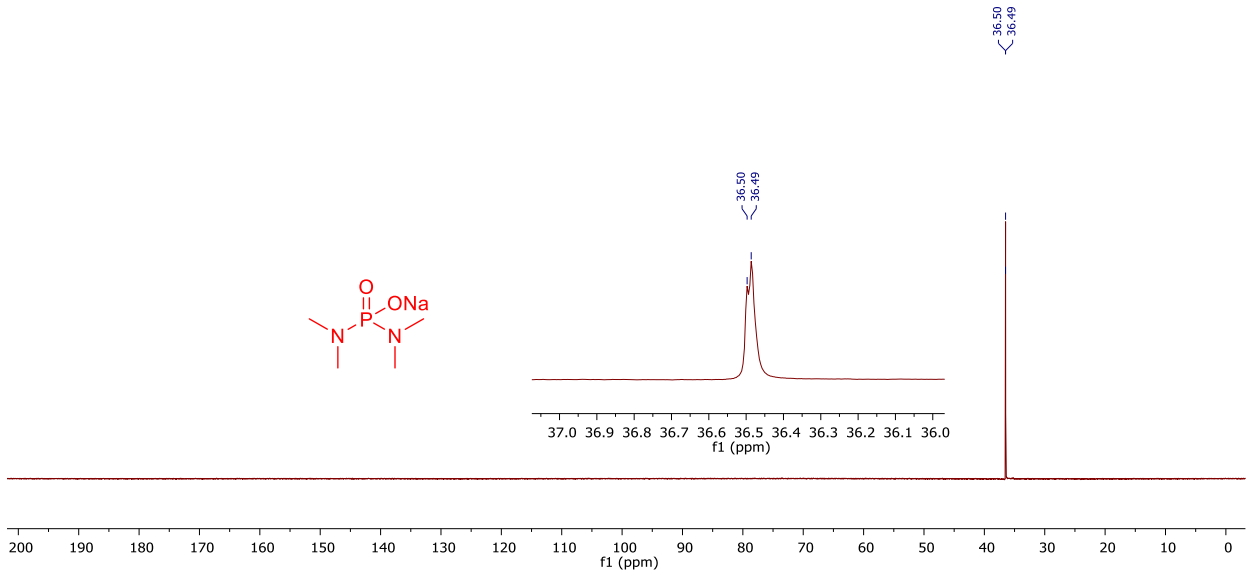


Sephadex column chromatography ($NaHCO_3$, 0.2-0.4M as eluent) afforded the cyclophosphate product **23** as sodium salt (119 mg, 85% from 98 mg of sodium shikimate). ^{1}H NMR (600 MHz, Deuterium Oxide) δ 6.40 – 6.37 (m, 1H), 5.02 (q, *J* = 4.4 Hz, 1H), 4.34 (ddd, *J* = 13.4, 8.7, 6.1 Hz, 1H), 3.99 (td, *J* = 8.7, 4.9 Hz, 1H), 2.67 (dd, *J* = 17.3, 4.9 Hz, 1H), 2.16 (ddt, *J* = 17.3, 9.0, 1.8 Hz, 1H); ^{13}C NMR (151 MHz, Deuterium Oxide) δ 174.08, 137.87, 125.83 (d, *J* = 9.1 Hz), 78.29, 72.55 (d, *J* = 3.0 Hz), 67.05 (d, *J* = 2.7 Hz), 30.36; ^{31}P NMR (162 MHz, Deuterium Oxide) δ 16.22; HRMS (ESI/Q-TOF) m/z calculated for $C_7H_9O_7P$ $[M-H]^-$ 235.0013, found 235.0013.

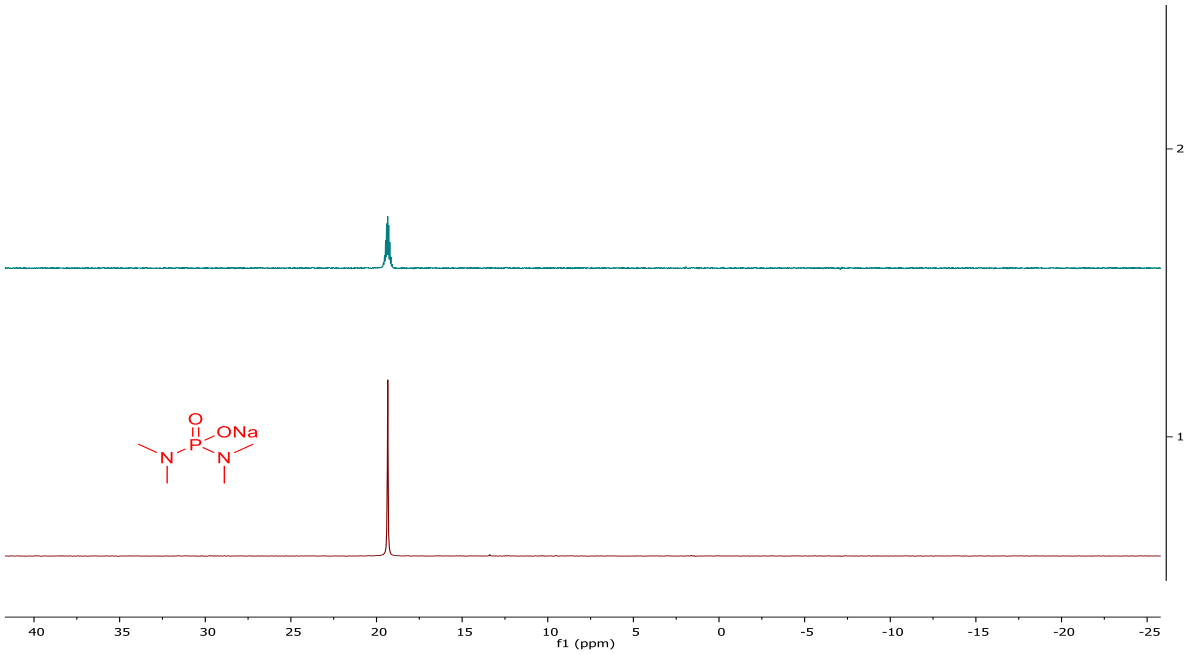
Supplementary NMR figures



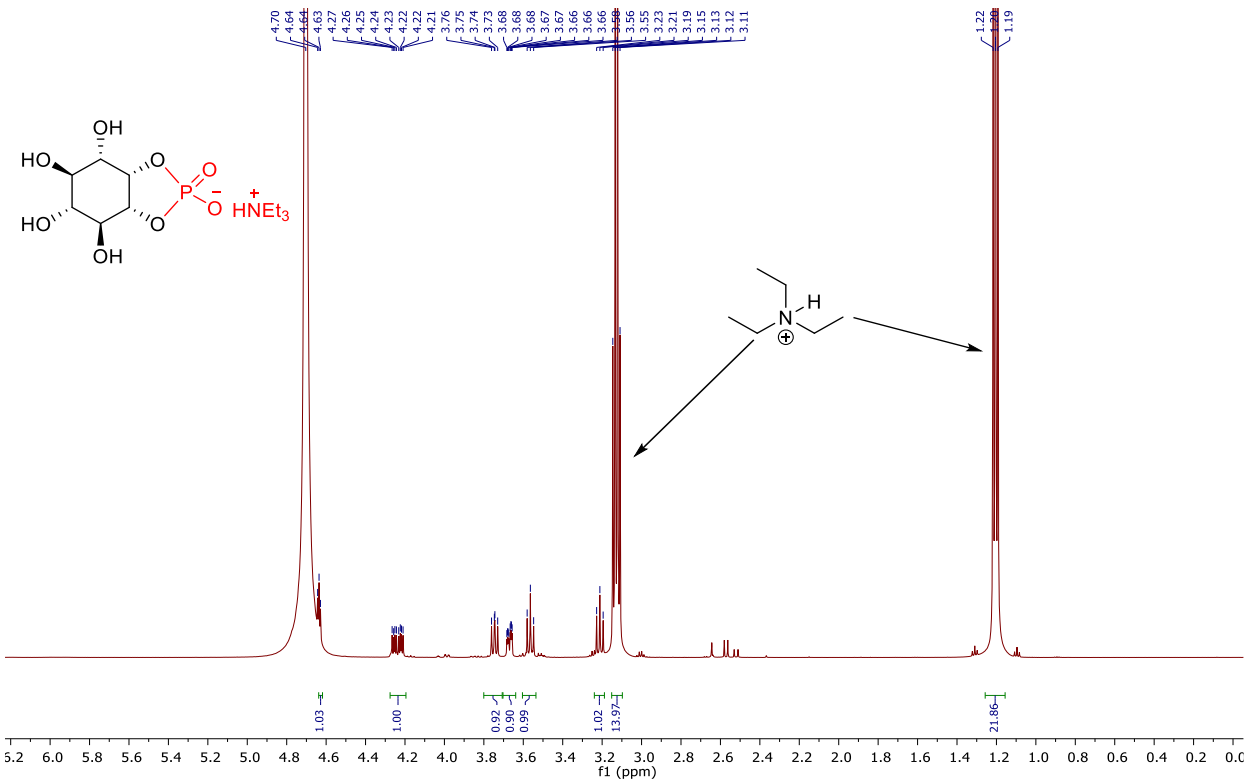
Supplementary Figure 2: ^{1}H NMR (600 MHz, D_2O) spectrum of compound **3**.



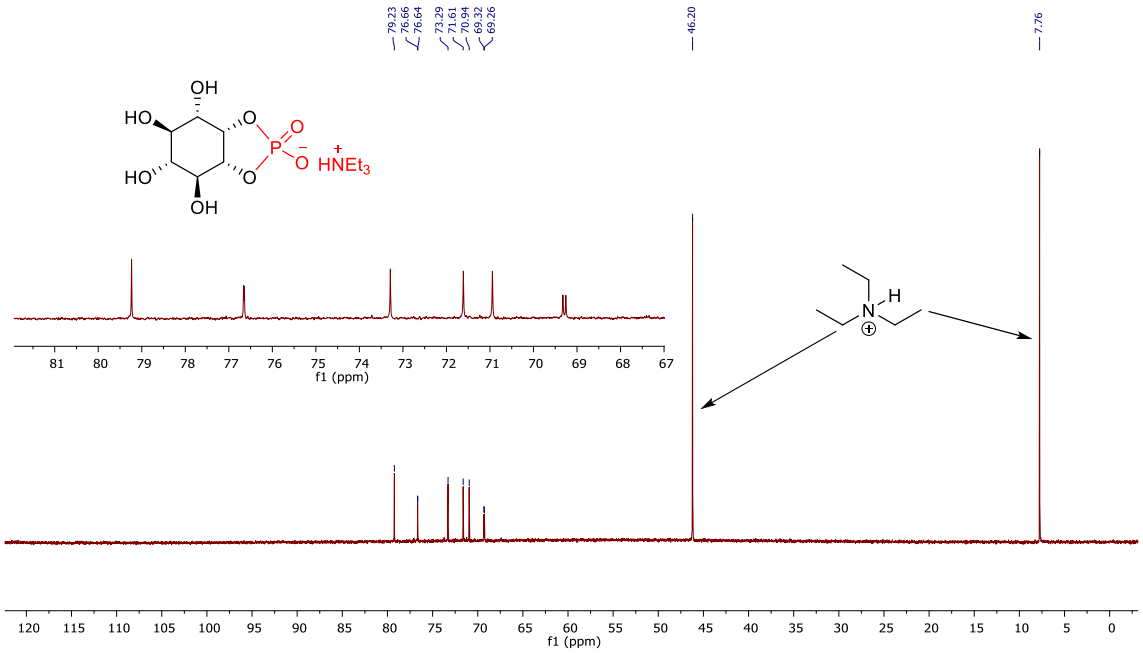
Supplementary Figure 3: ^{13}C NMR (101 MHz, D_2O) spectrum of compound **3**.



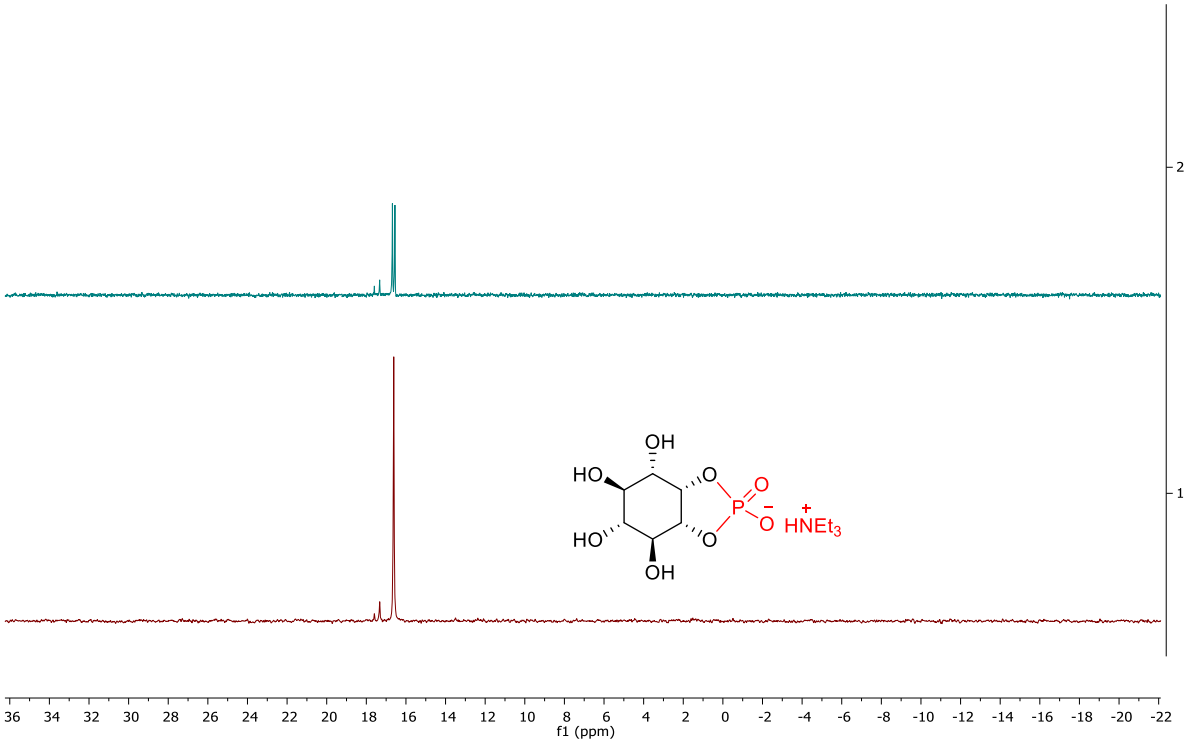
Supplementary Figure 4 ^{31}P NMR (162 MHz, D_2O) spectrum of compound **3** ({H-decoupled} = bottom spectrum, {H-coupled} = top spectrum).



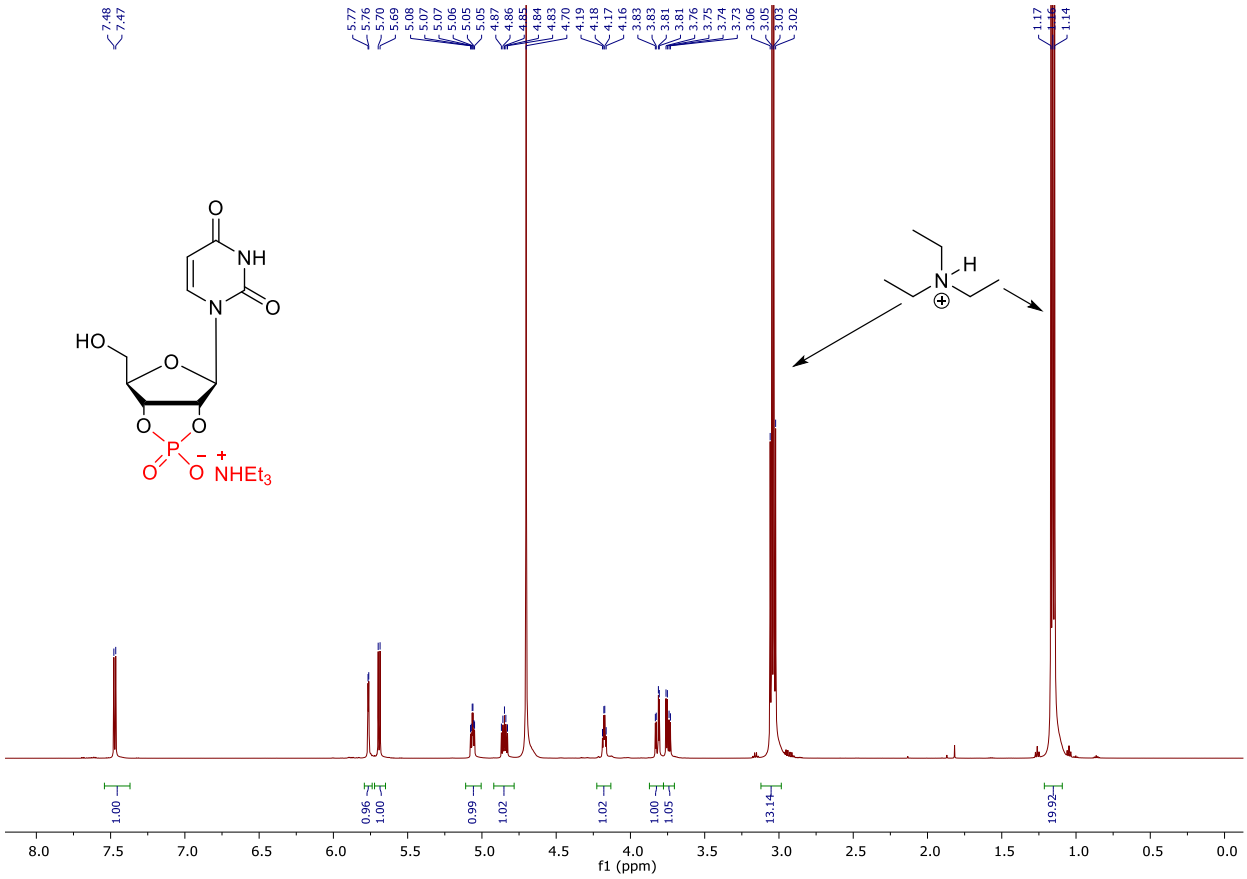
Supplementary Figure 5: ^{1}H NMR (600 MHz, D_2O) spectrum of compound **4**.



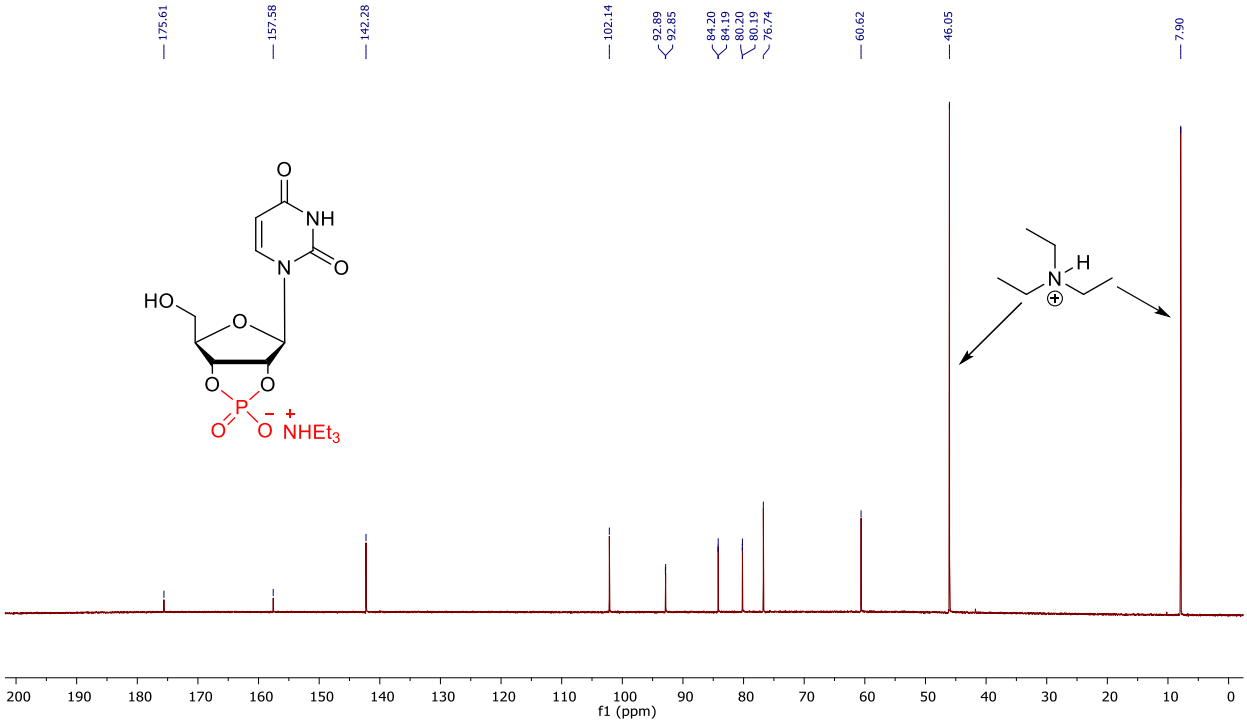
Supplementary Figure 6: ^{13}C NMR (151 MHz, D_2O) spectrum of compound **4**.



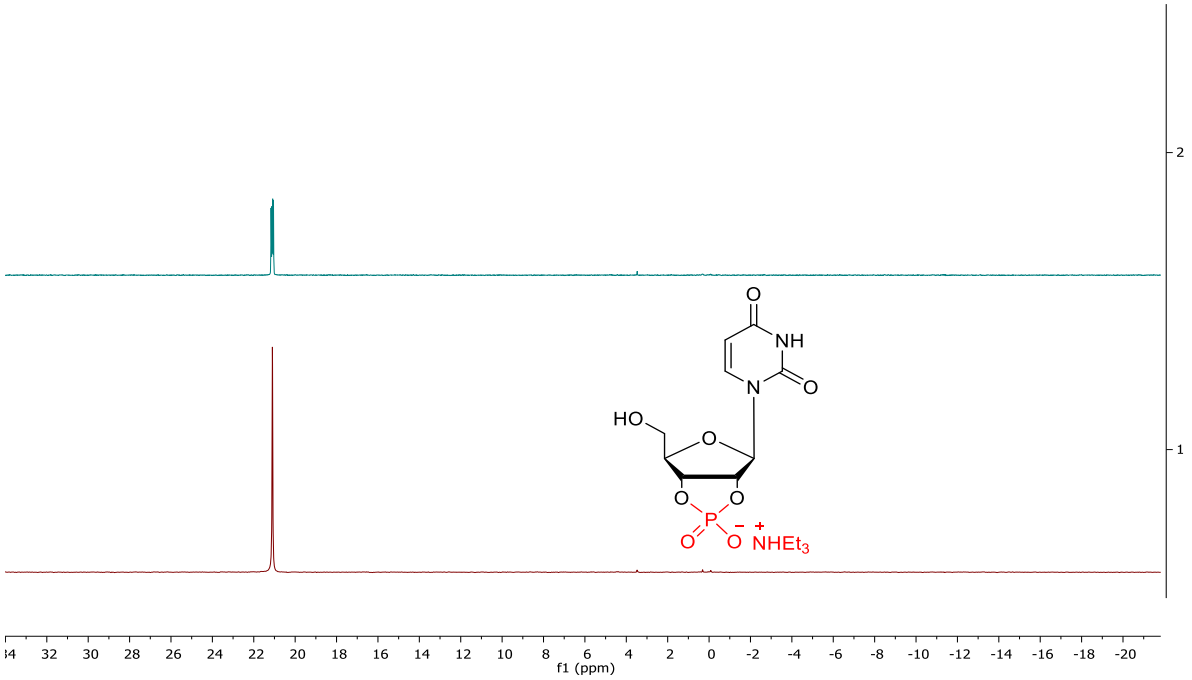
Supplementary Figure 7: ^{31}P NMR (162 MHz, D_2O) spectrum of compound **4** ({H-decoupled} = bottom spectrum, {H-coupled} = top spectrum).



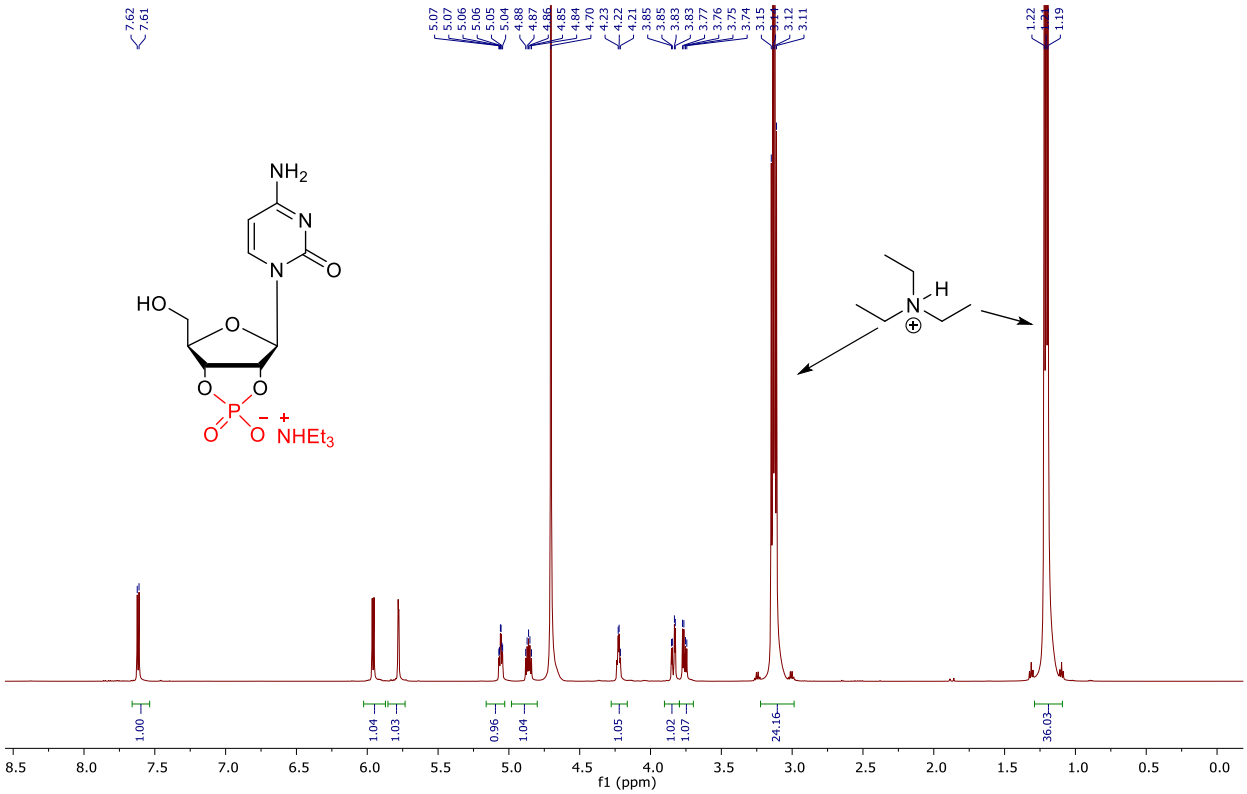
Supplementary Figure 8: ^{1}H NMR (600 MHz, D_2O) spectrum of compound **5**.



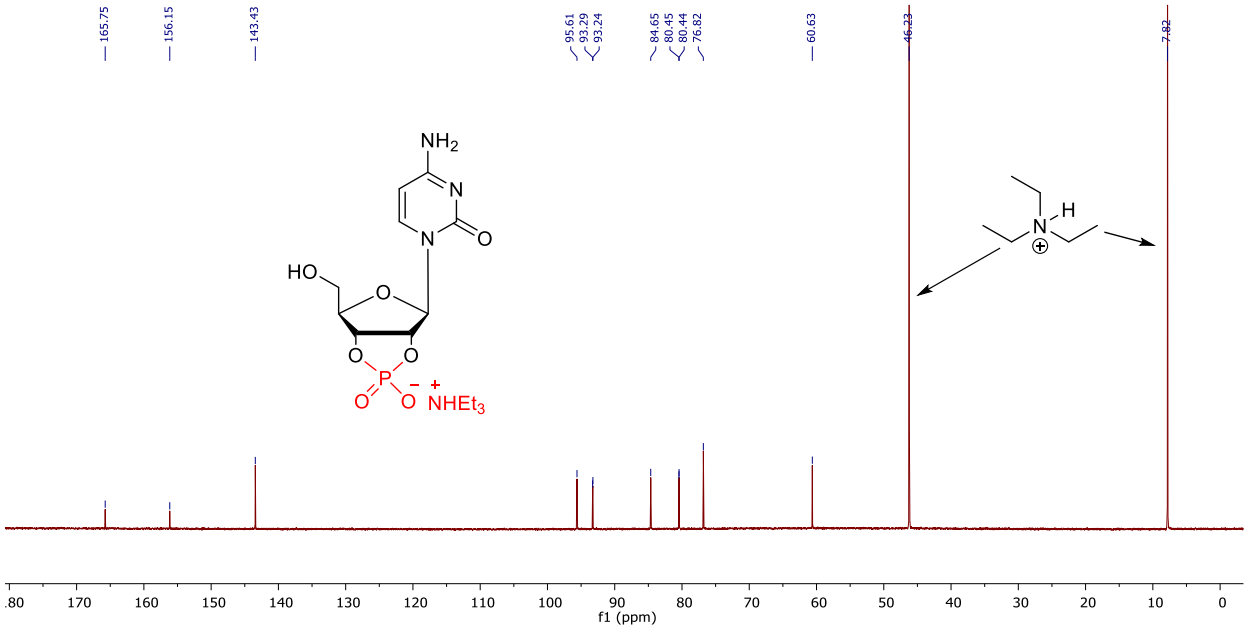
Supplementary Figure 9: ^{13}C NMR (151 MHz, D_2O) spectrum of compound **5**.



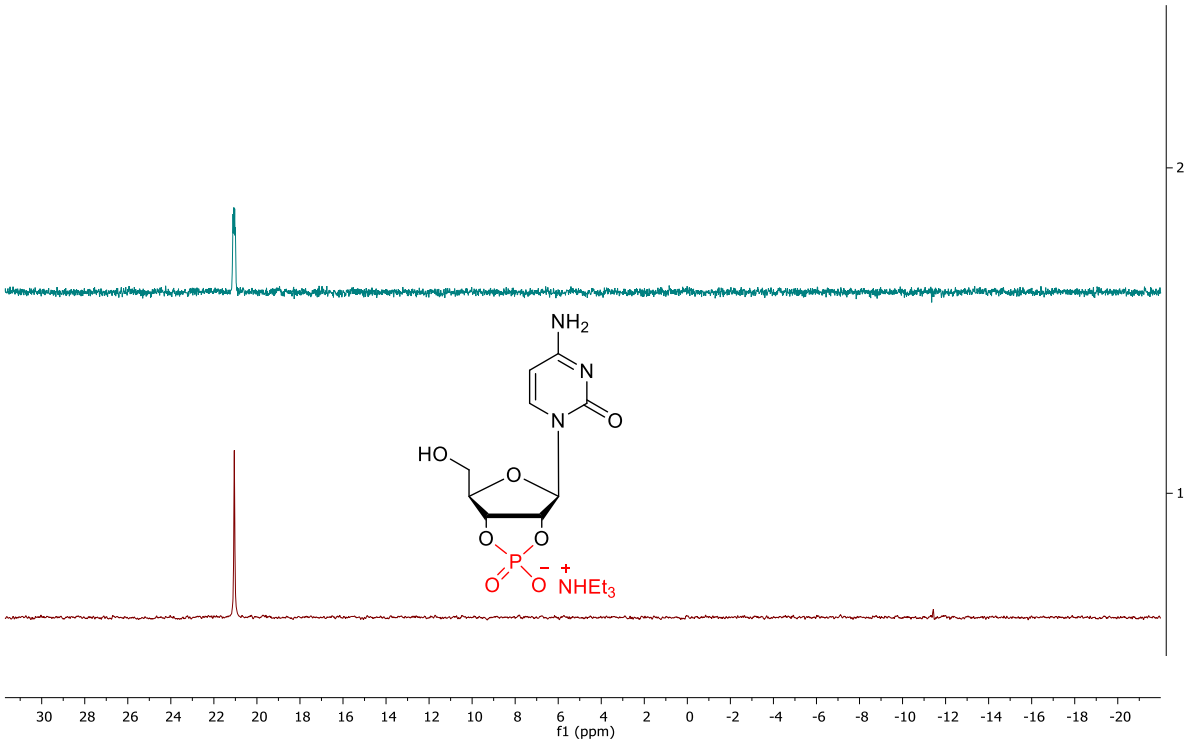
Supplementary Figure 10: ^{31}P NMR (162 MHz, D_2O) spectrum of compound **5** ({H-decoupled} = bottom spectrum, {H-coupled} = top spectrum).



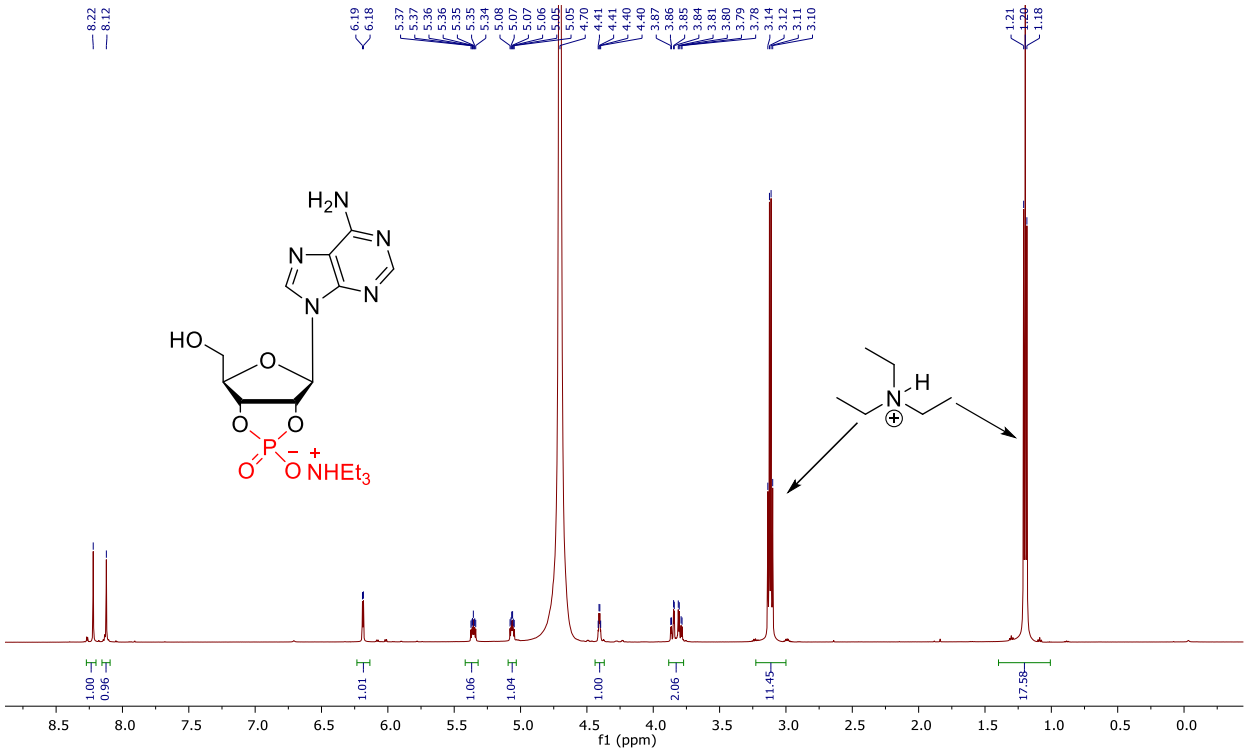
Supplementary Figure 11: ^{1}H NMR (600 MHz, D_2O) spectrum of compound **6**.



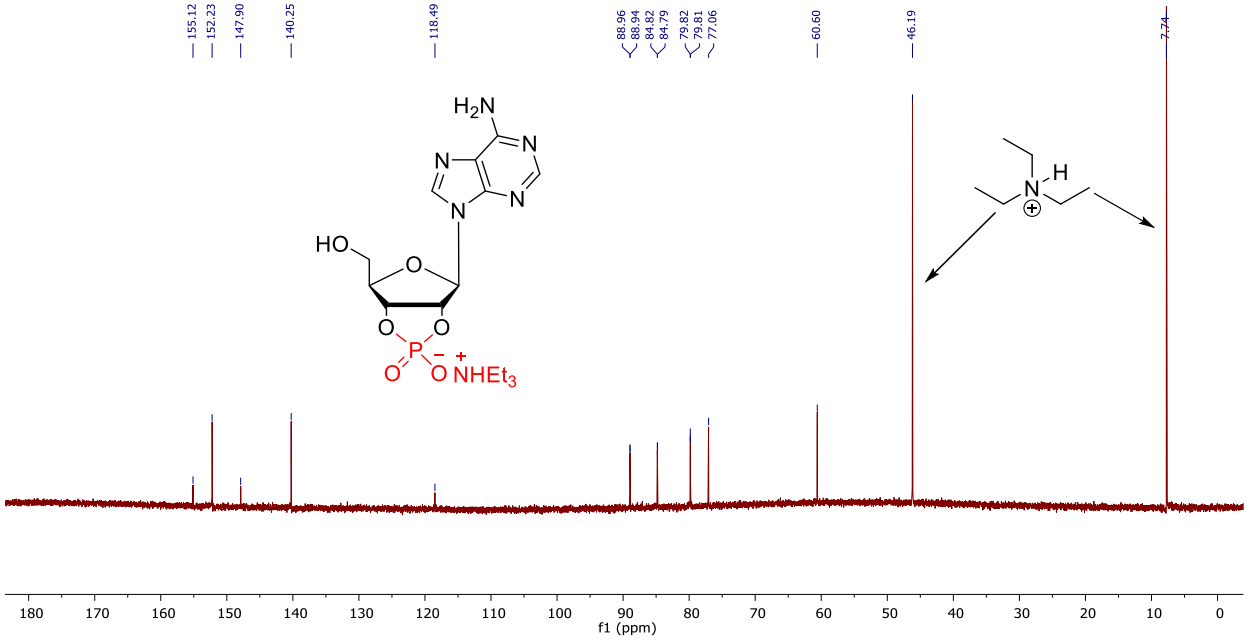
Supplementary Figure 12: ^{13}C NMR (151 MHz, D_2O) spectrum of compound **6**.



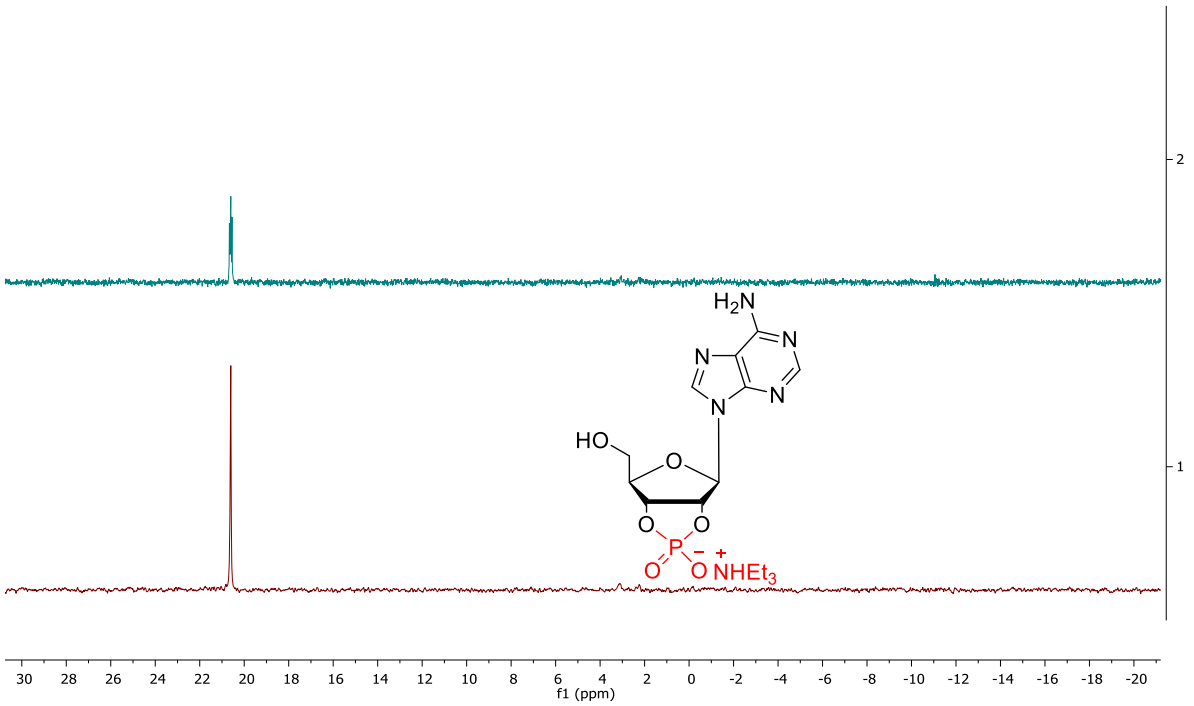
Supplementary Figure 13: ^{31}P NMR (162 MHz, D_2O) spectrum of compound **6** ({H-decoupled} = bottom spectrum, {H-coupled} = top spectrum).



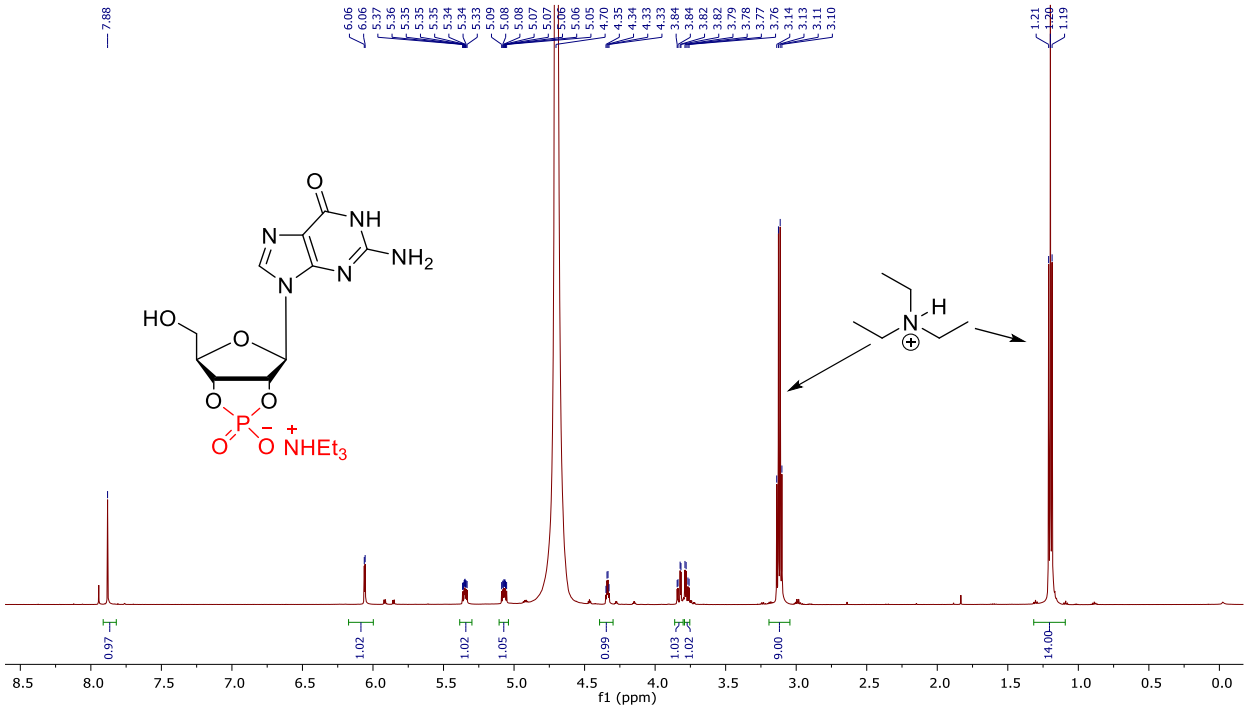
Supplementary Figure 14: ^{1}H NMR (600 MHz, D_2O) spectrum of compound **7**.



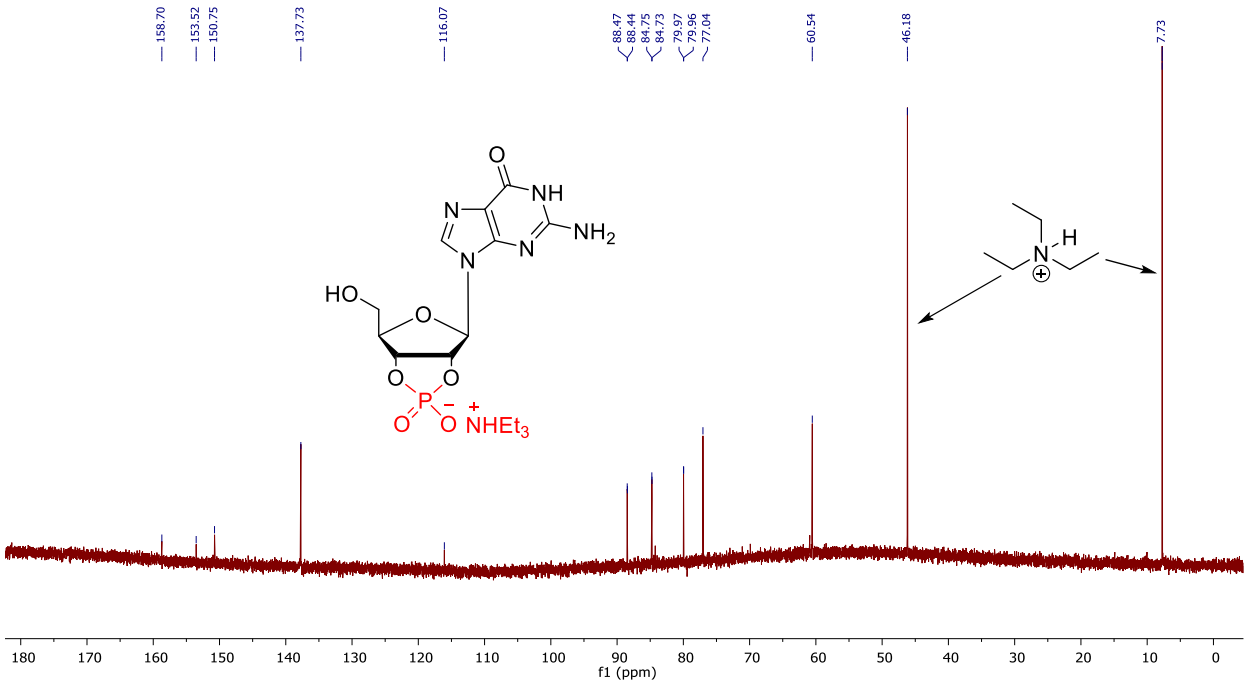
Supplementary Figure 15: ^{13}C NMR (151 MHz, D_2O) spectrum of compound **7**.



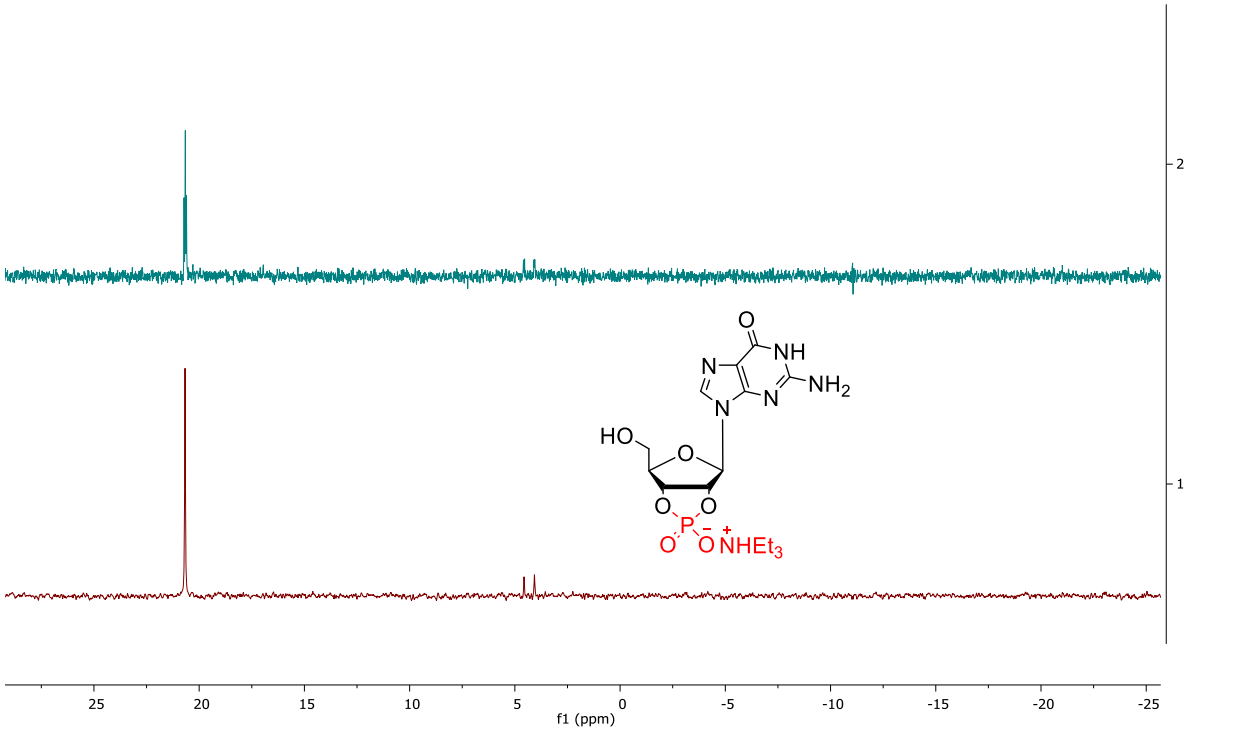
Supplementary Figure 16: ^{31}P NMR (162 MHz, D_2O) spectrum of compound **7** ({H-decoupled} = bottom spectrum, {H-coupled} = top spectrum).



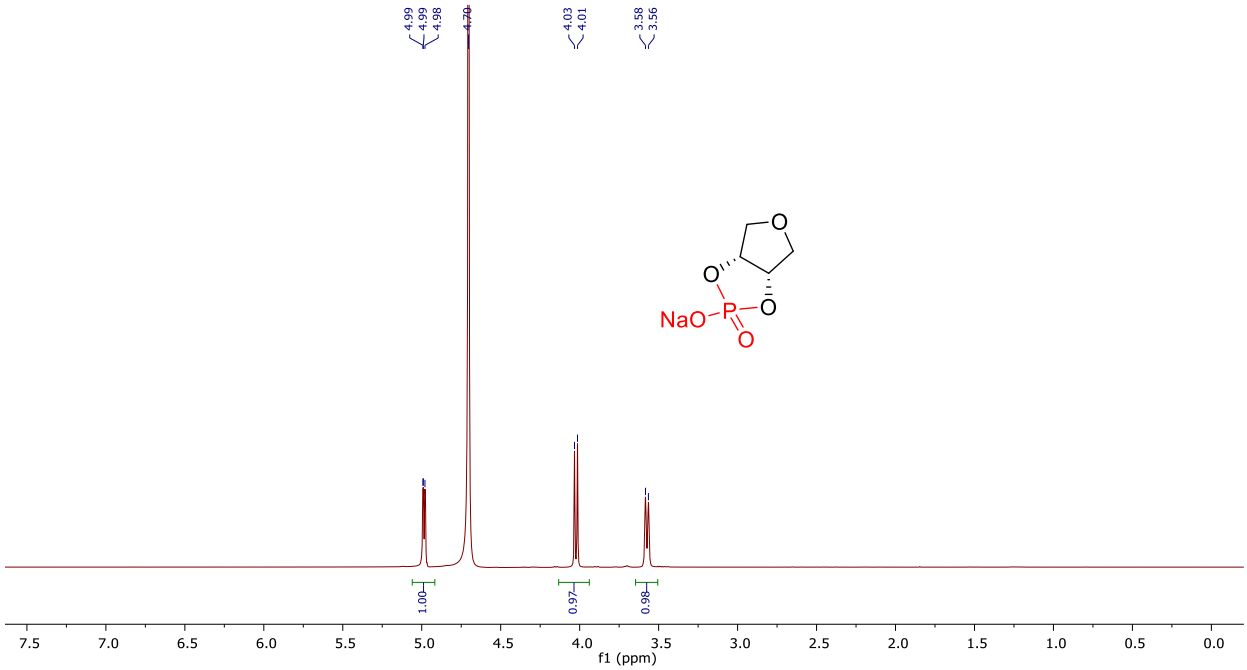
Supplementary Figure 17: ^{1}H NMR (600 MHz, D_2O) spectrum of compound **8**.



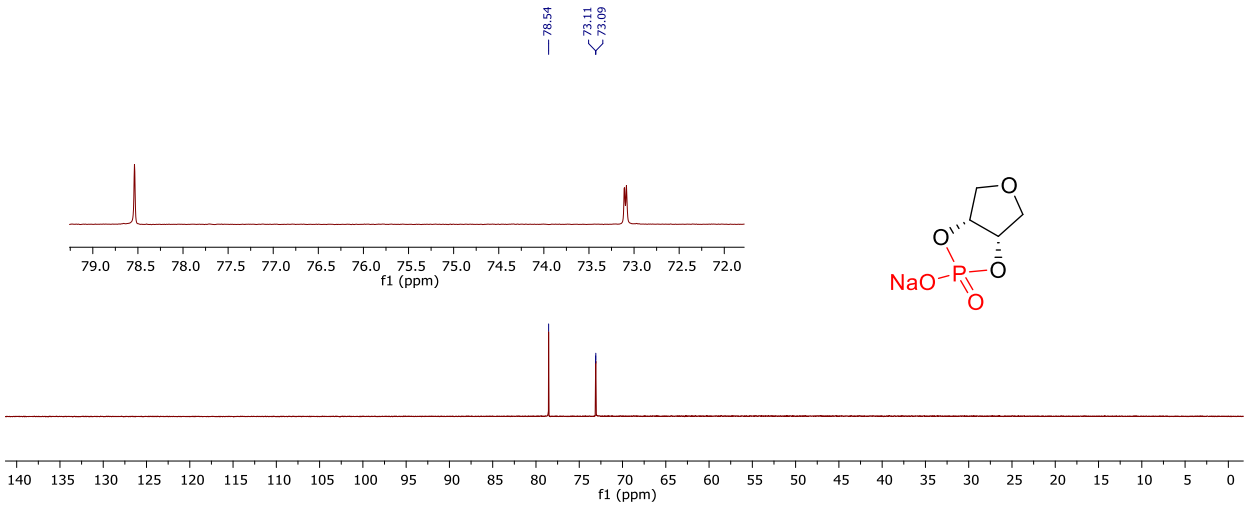
Supplementary Figure 18: ^{13}C NMR (151 MHz, D_2O) spectrum of compound **8**.



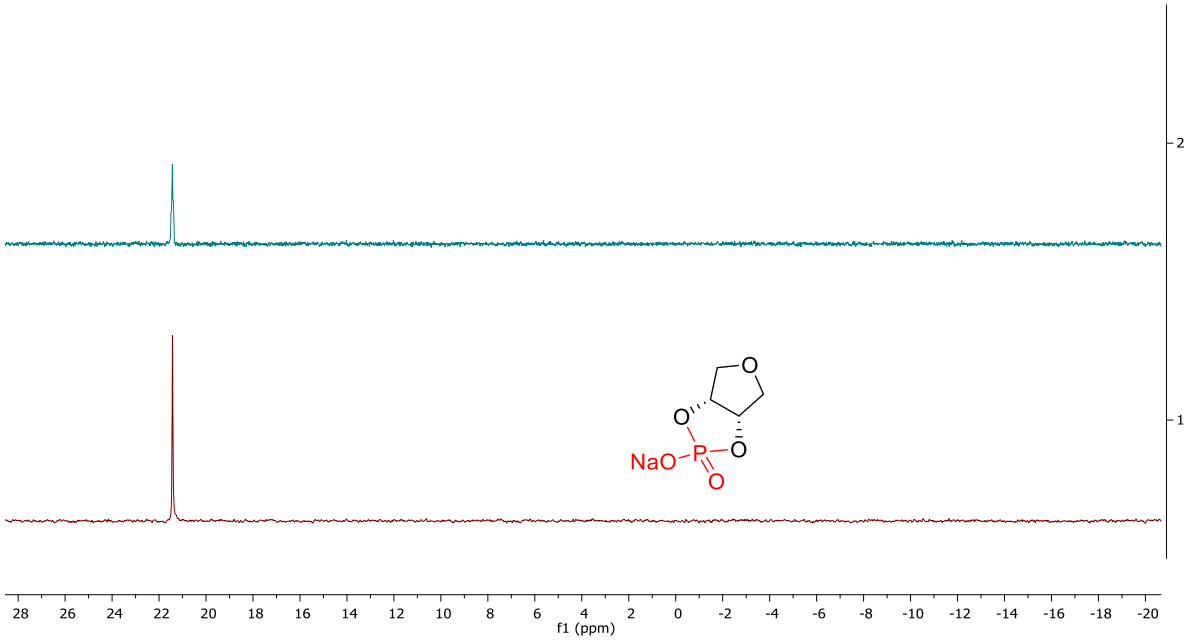
Supplementary Figure 19: ^{31}P NMR (162 MHz, D_2O) spectrum of compound **8** ({H-decoupled} = bottom spectrum, {H-coupled} = top spectrum).



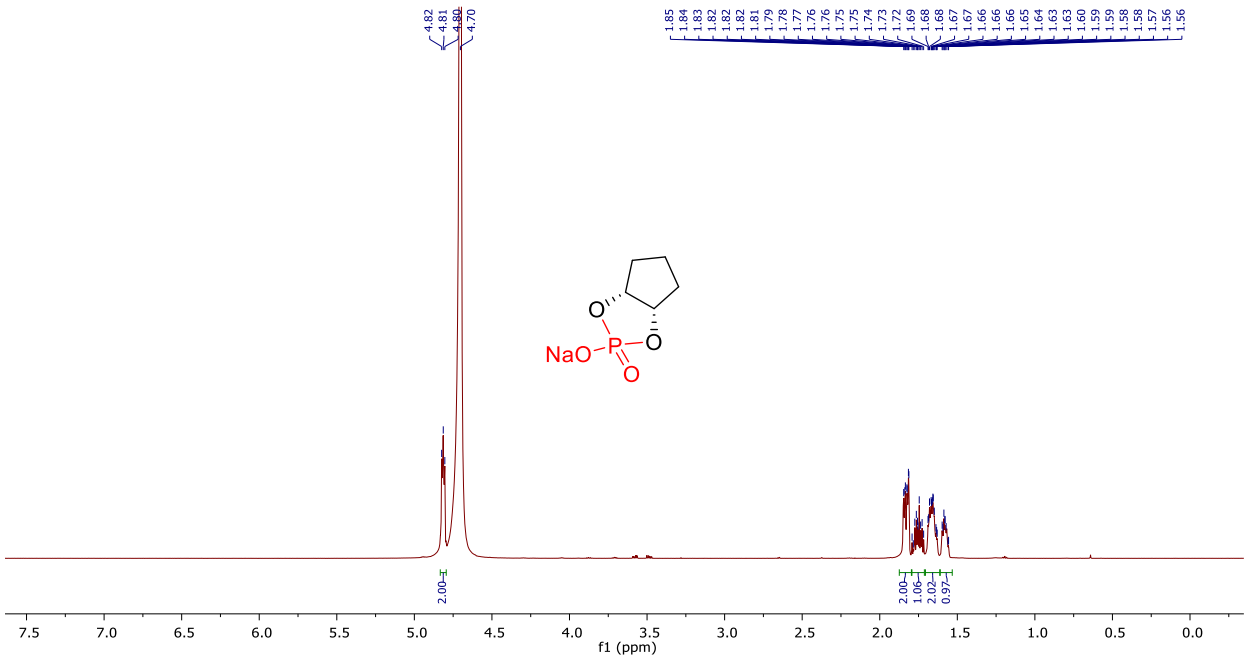
Supplementary Figure 20: ^{1}H NMR (600 MHz, D_2O) spectrum of compound **9**.



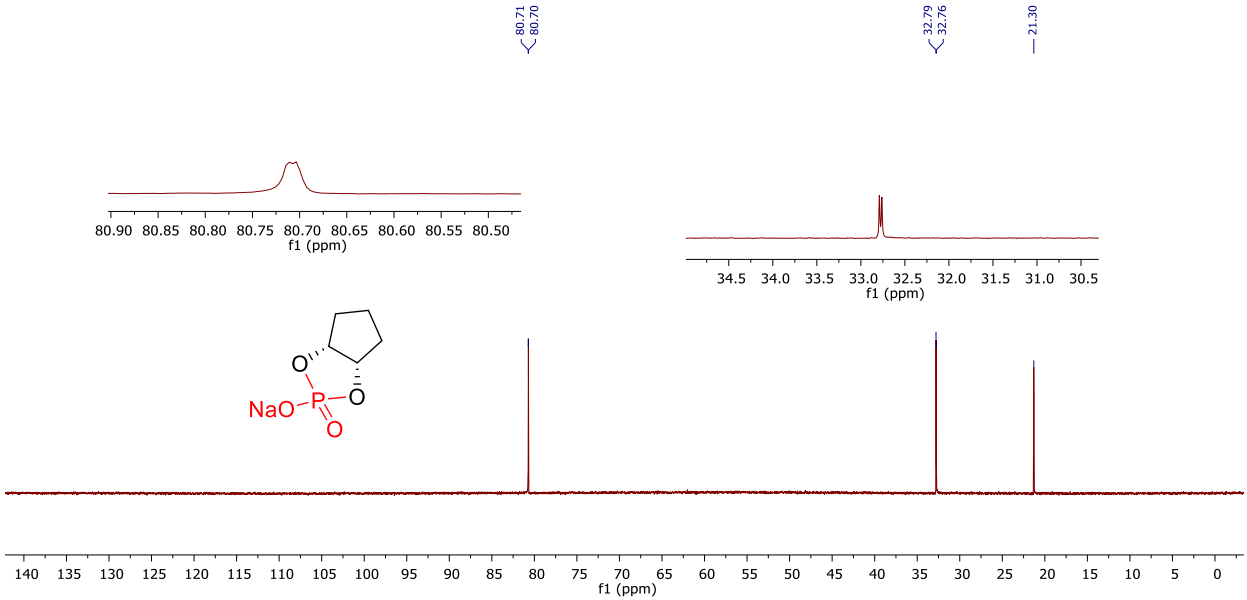
Supplementary Figure 21: ^{13}C NMR (151 MHz, D_2O) spectrum of compound **9**.



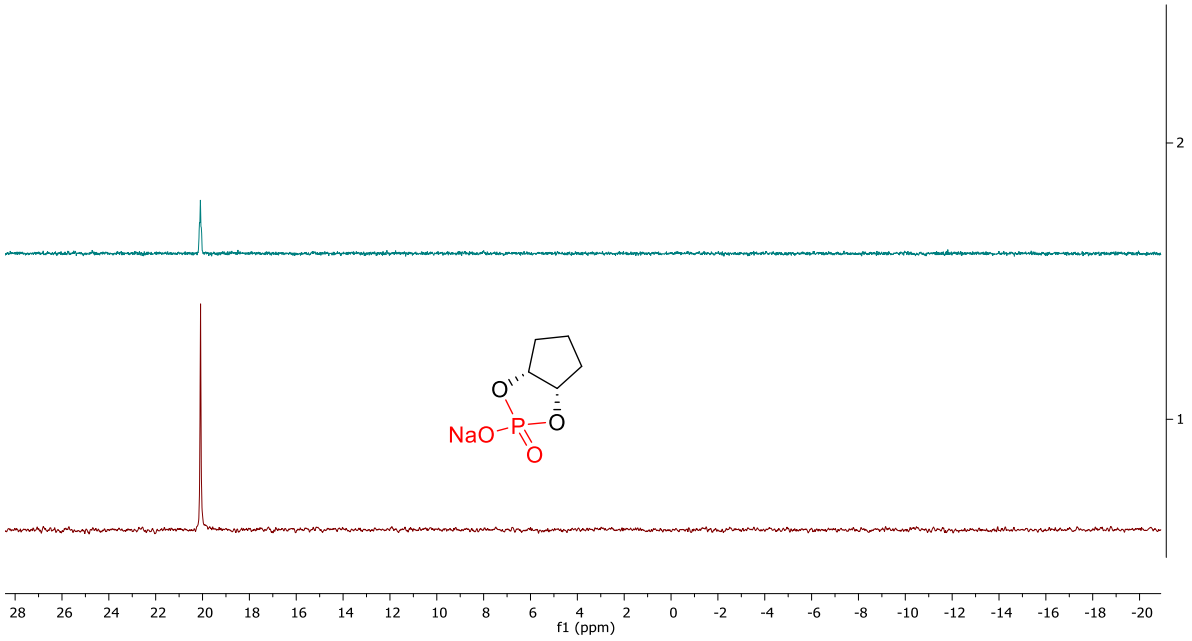
Supplementary Figure 22: ^{31}P NMR (162 MHz, D_2O) spectrum of compound **9** ({H-decoupled} = bottom spectrum, {H-coupled} = top spectrum).



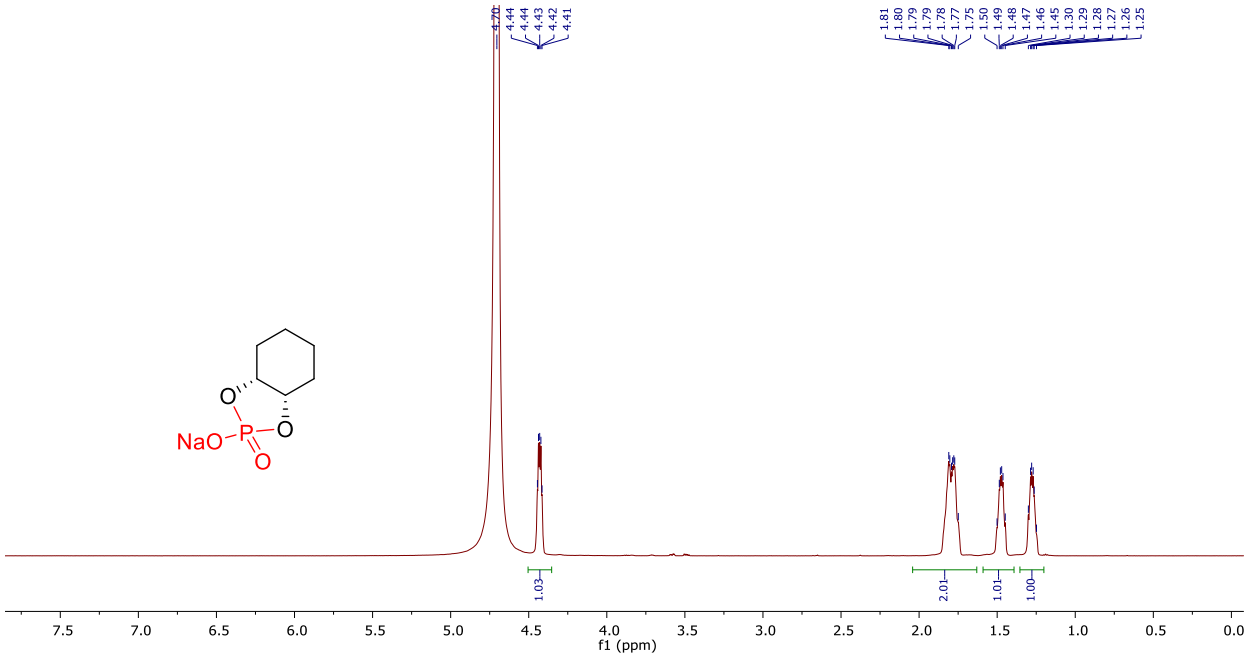
Supplementary Figure 23: ^{1}H NMR (600 MHz, D_2O) spectrum of compound **10**.



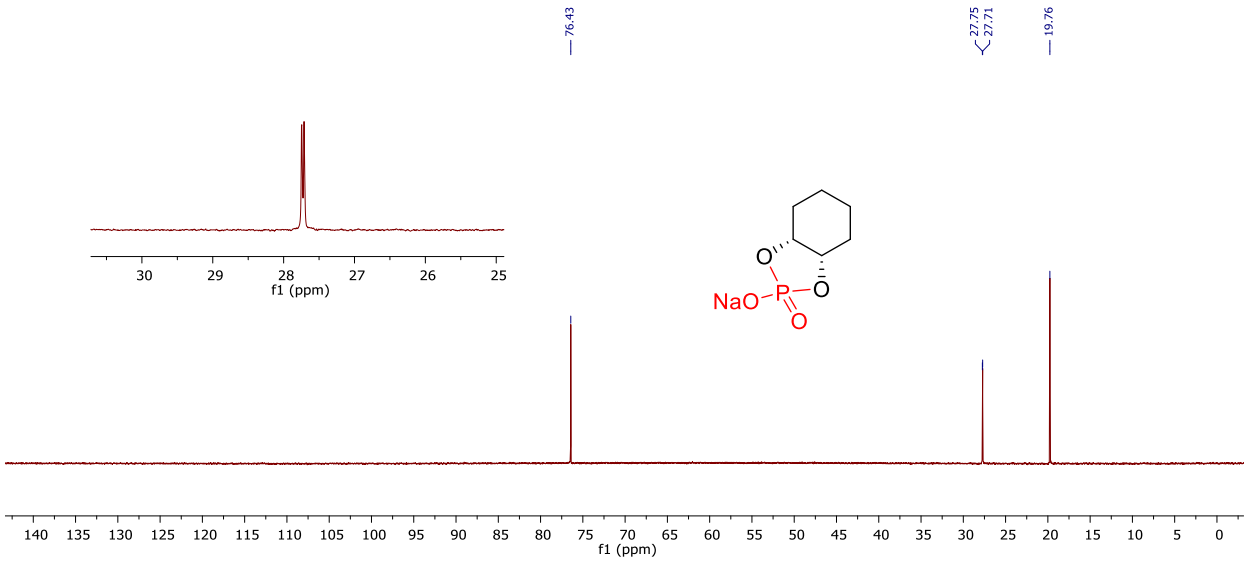
Supplementary Figure 24: ^{13}C NMR (151 MHz, D_2O) spectrum of compound **10**.



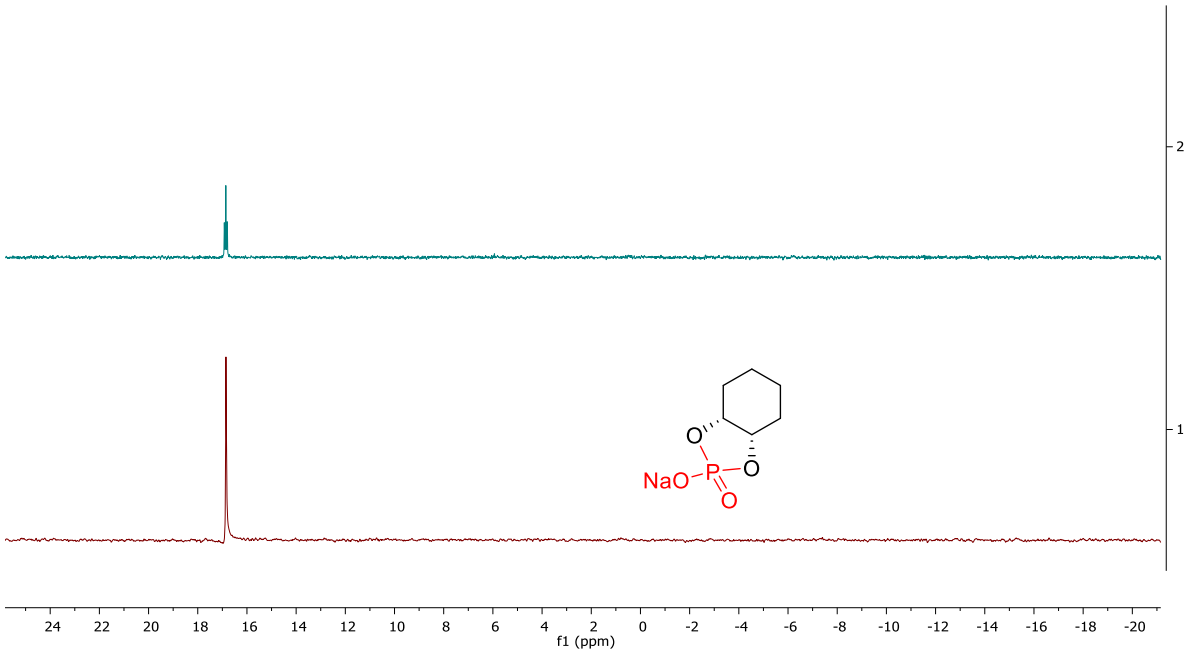
Supplementary Figure 25: ^{31}P NMR (162 MHz, D_2O) spectrum of compound **10** ({H-decoupled} = bottom spectrum, {H-coupled} = top spectrum).



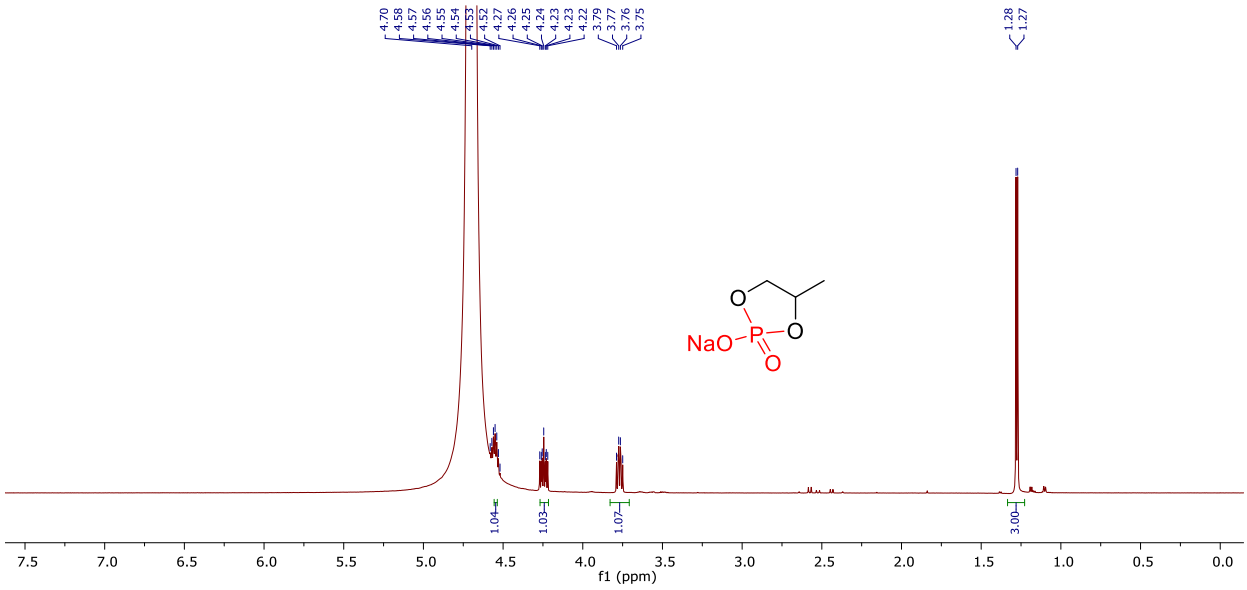
Supplementary Figure 26: ^{1}H NMR (600 MHz, D_2O) spectrum of compound **11**.



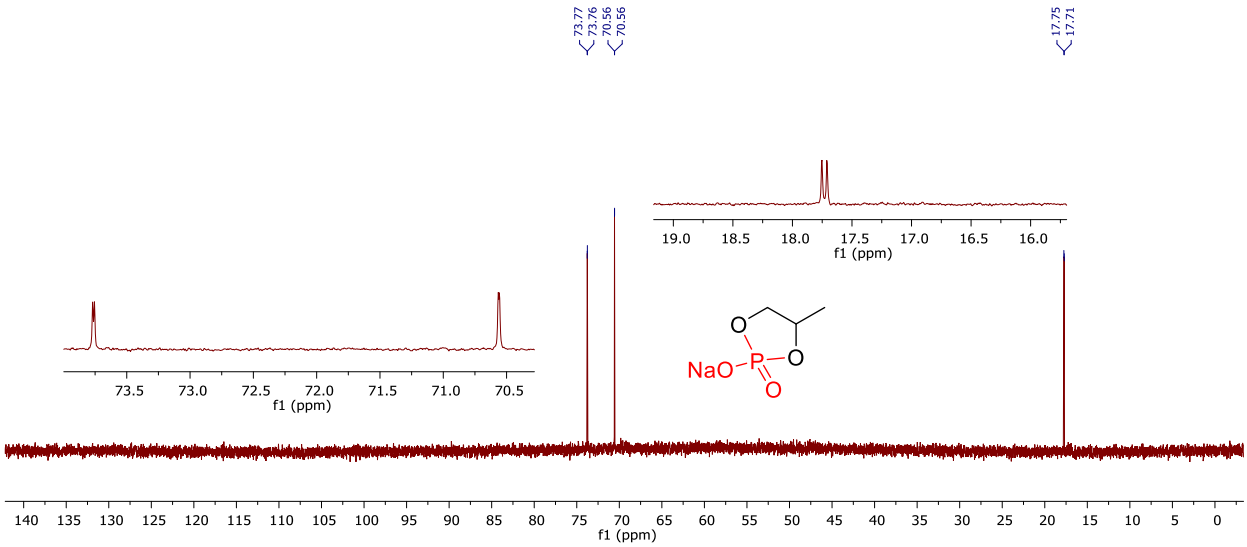
Supplementary Figure 27: ^{13}C NMR (151 MHz, D_2O) spectrum of compound **11**.



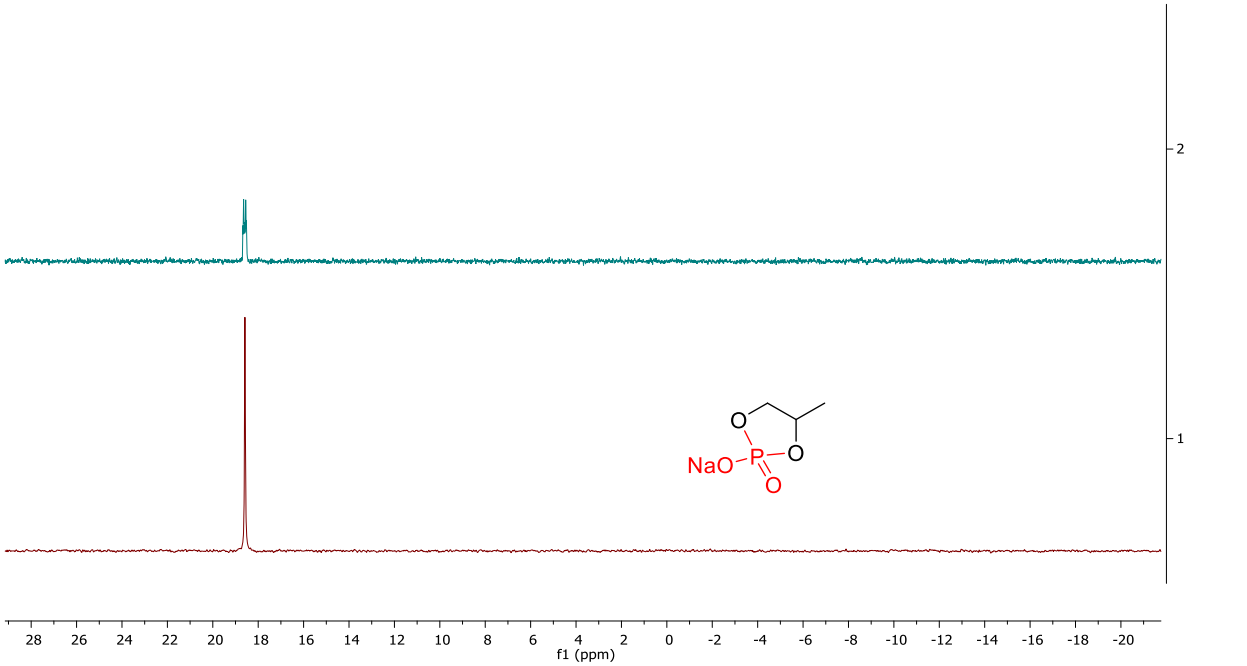
Supplementary Figure 28: ^{31}P NMR (162 MHz, D_2O) spectrum of compound **11** ({H-decoupled} = bottom spectrum, {H-coupled} = top spectrum).



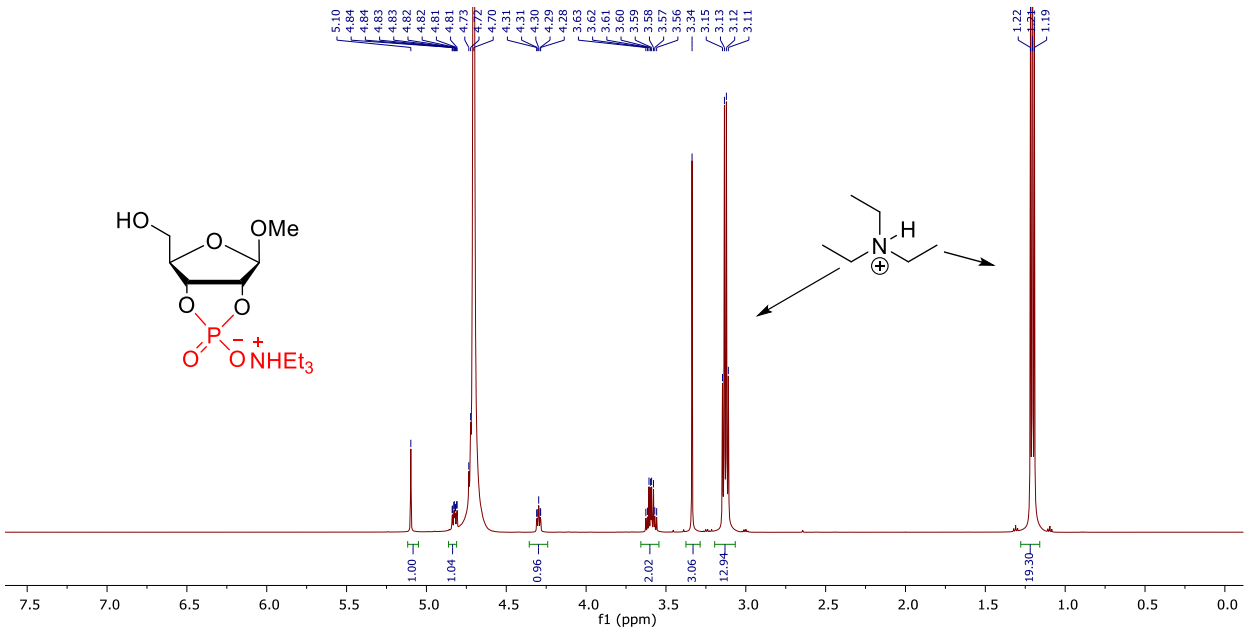
Supplementary Figure 29: ^{1}H NMR (600 MHz, D_2O) spectrum of compound **12**.



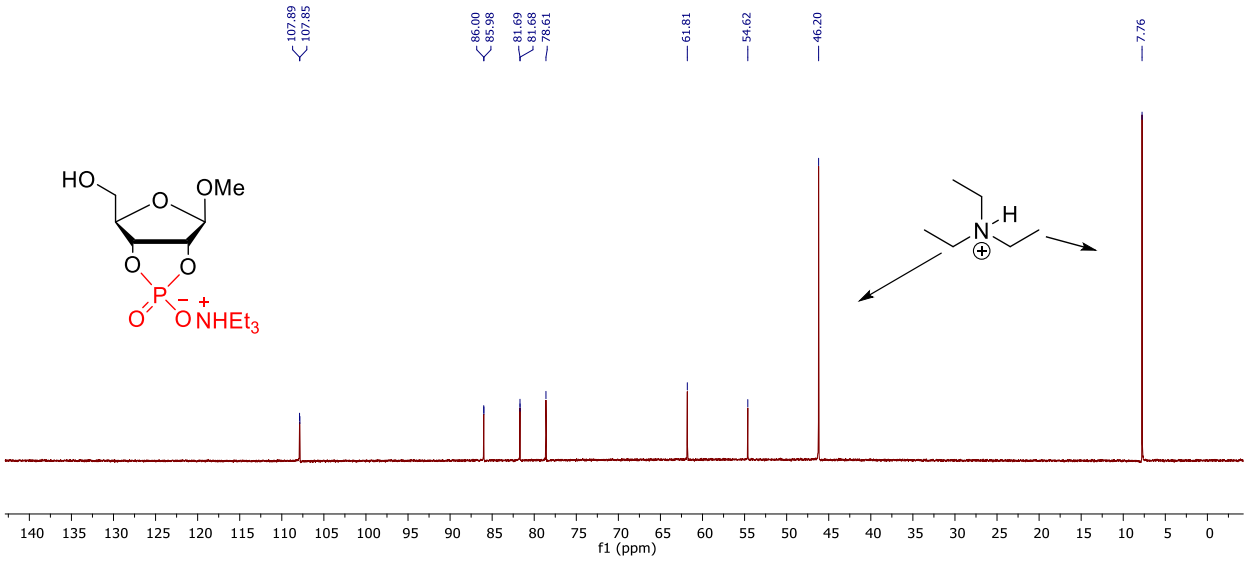
Supplementary Figure 30: ^{13}C NMR (151 MHz, D_2O) spectrum of compound **12**.



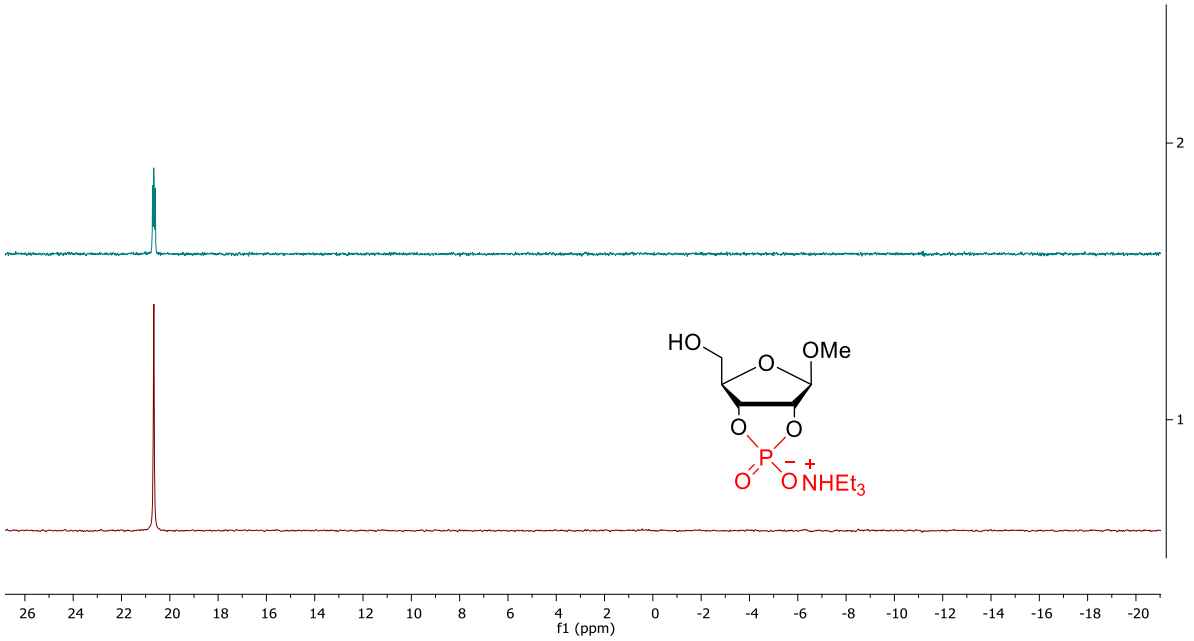
Supplementary Figure 31: ^{31}P NMR (162 MHz, D_2O) spectrum of compound **12** ({H-decoupled} = bottom spectrum, {H-coupled} = top spectrum).



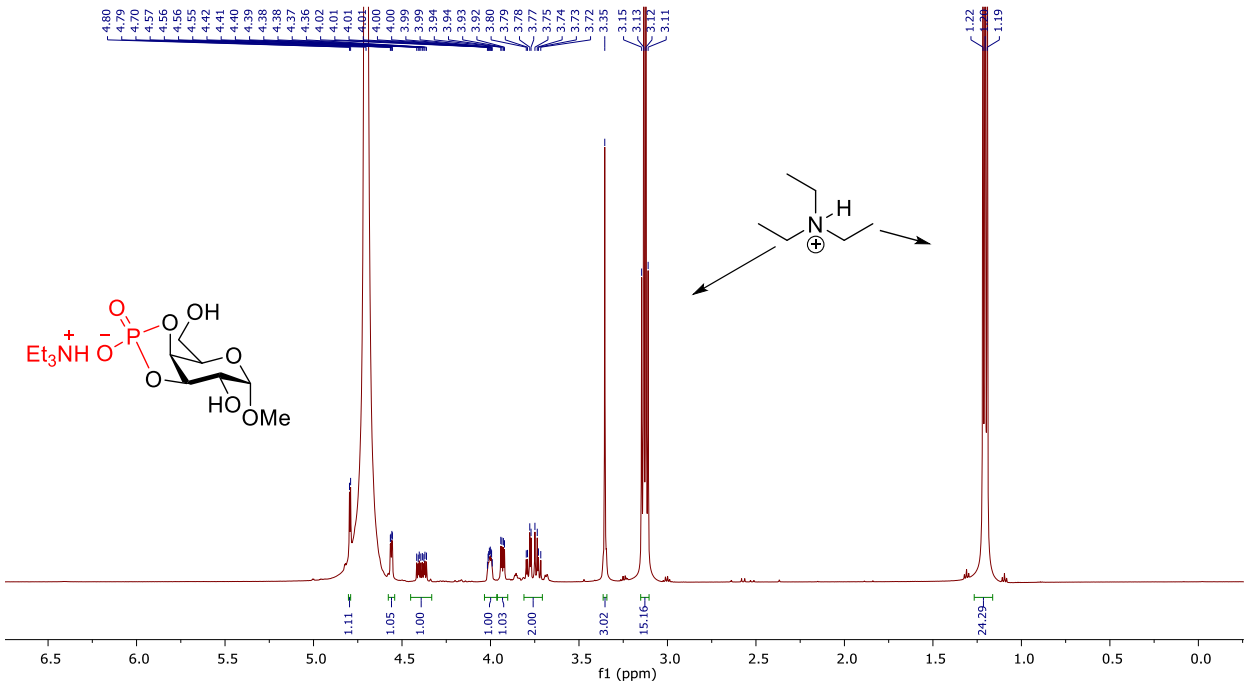
Supplementary Figure 32: ^{1}H NMR (600 MHz, D_2O) spectrum of compound **13**.



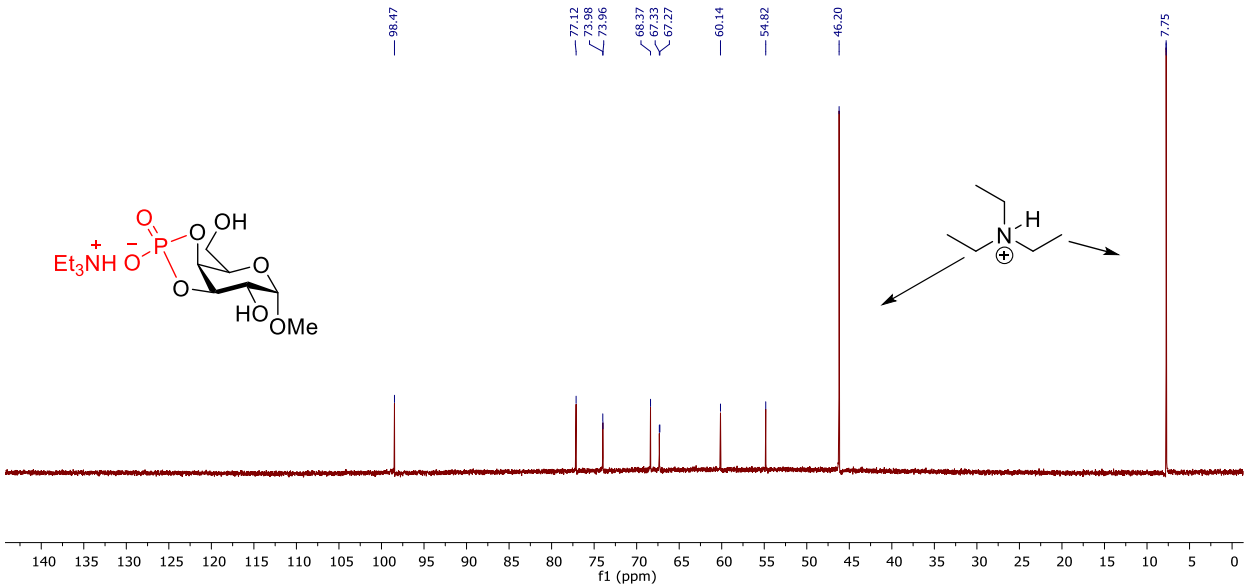
Supplementary Figure 33: ^{13}C NMR (151 MHz, D_2O) spectrum of compound **13**.



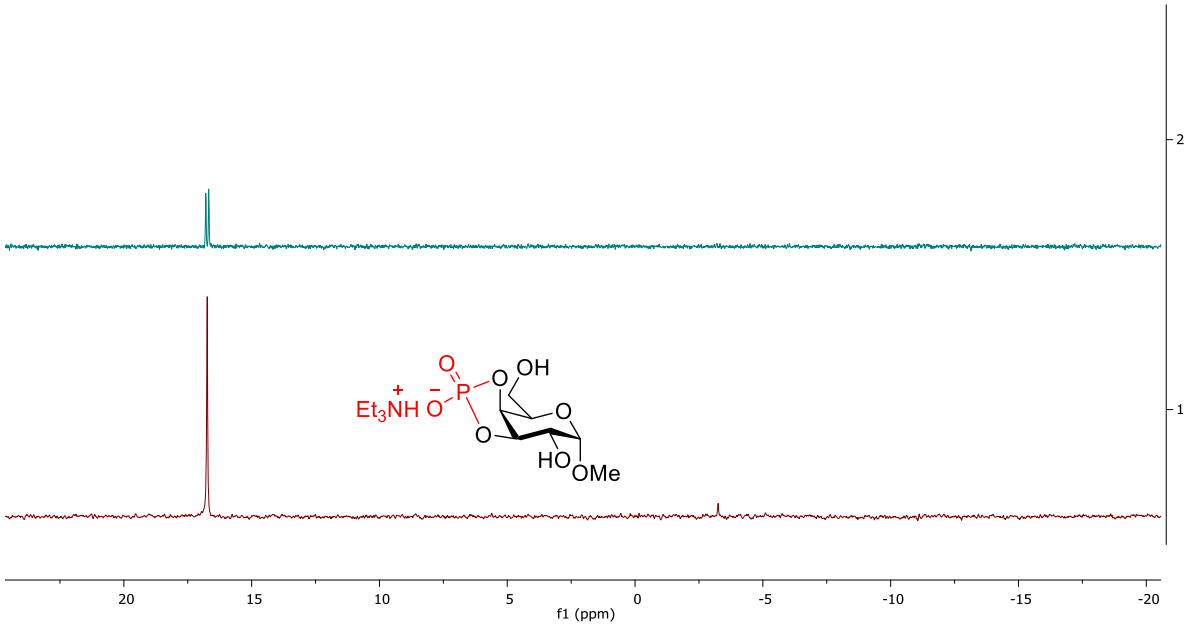
Supplementary Figure 34: ^{31}P NMR (162 MHz, D_2O) spectrum of compound **13** ({H-decoupled} = bottom spectrum, {H-coupled} = top spectrum).



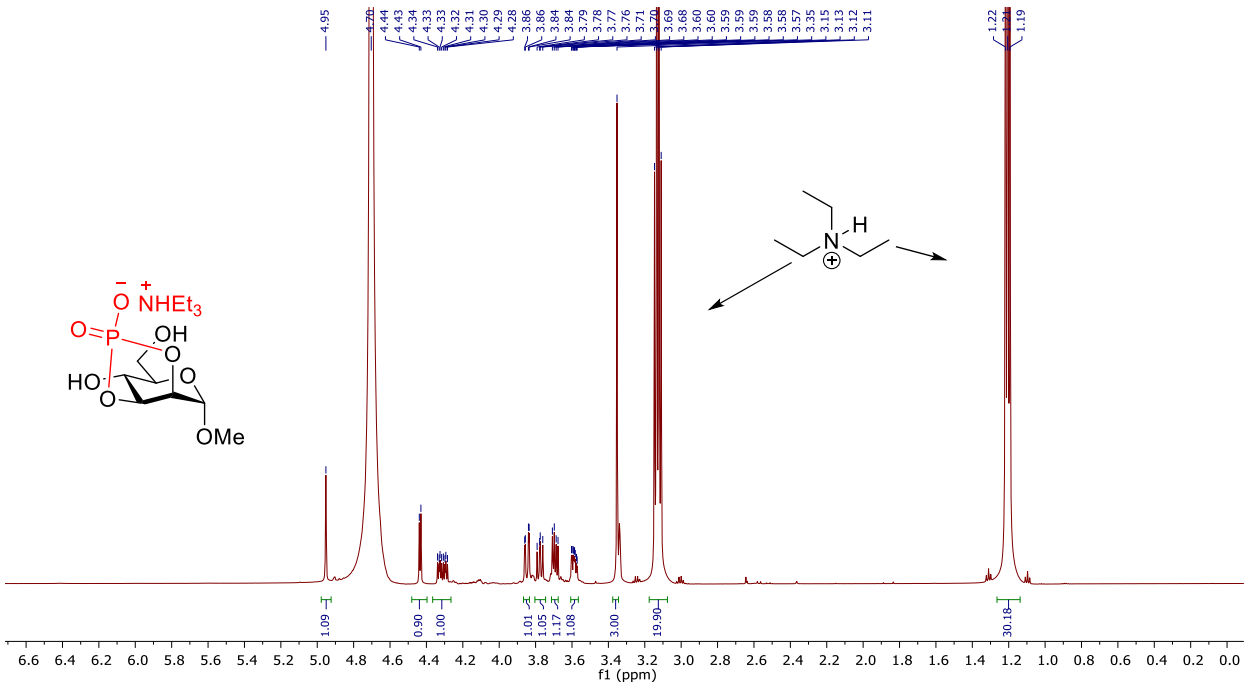
Supplementary Figure 35: ^{1}H NMR (600 MHz, D_2O) spectrum of compound **14**.



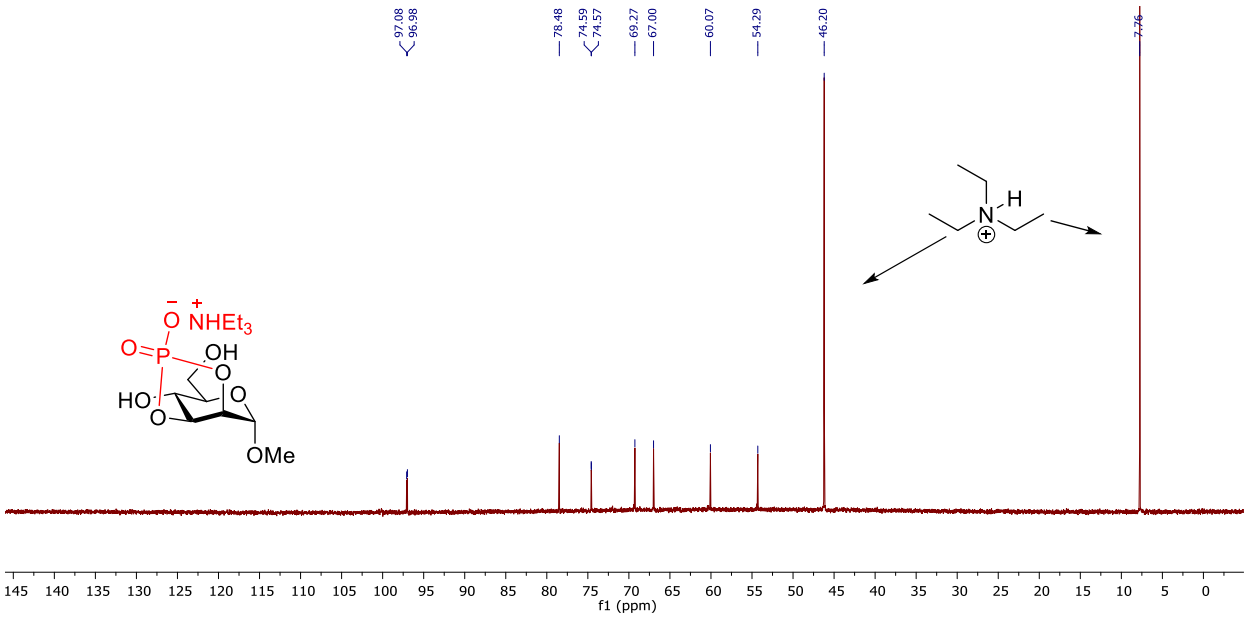
Supplementary Figure 36: ^{13}C NMR (151 MHz, D_2O) spectrum of compound **14**.



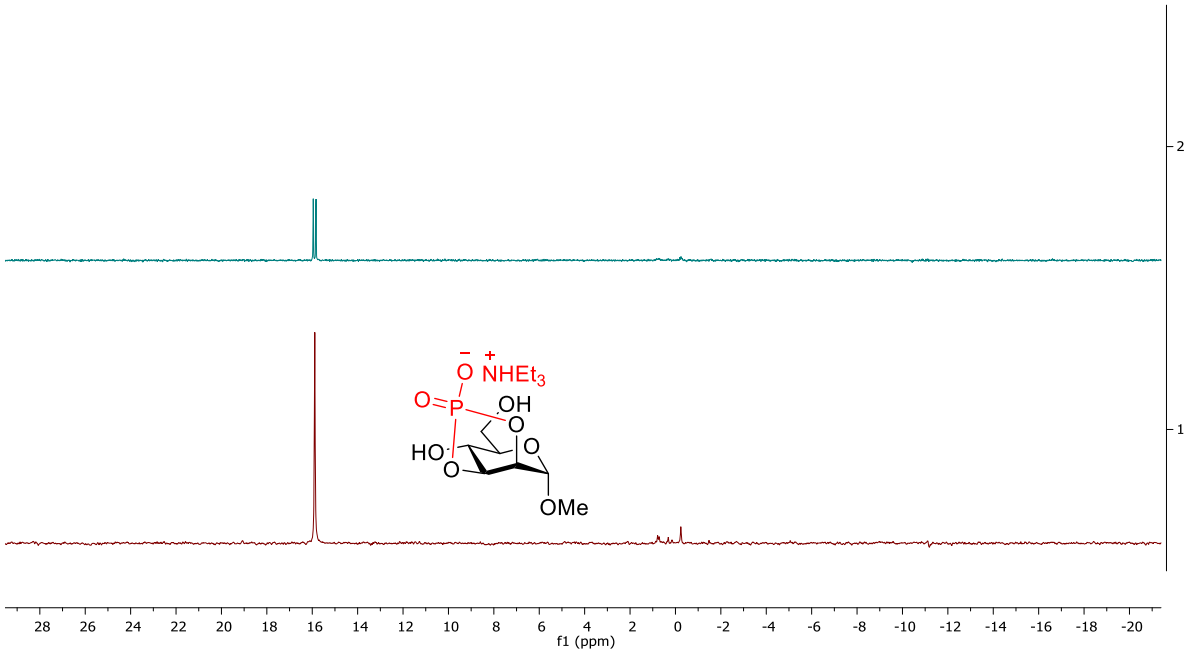
Supplementary Figure 37: ^{31}P NMR (162 MHz, D_2O) spectrum of compound **14** ({H-decoupled} = bottom spectrum, {H-coupled} = top spectrum).



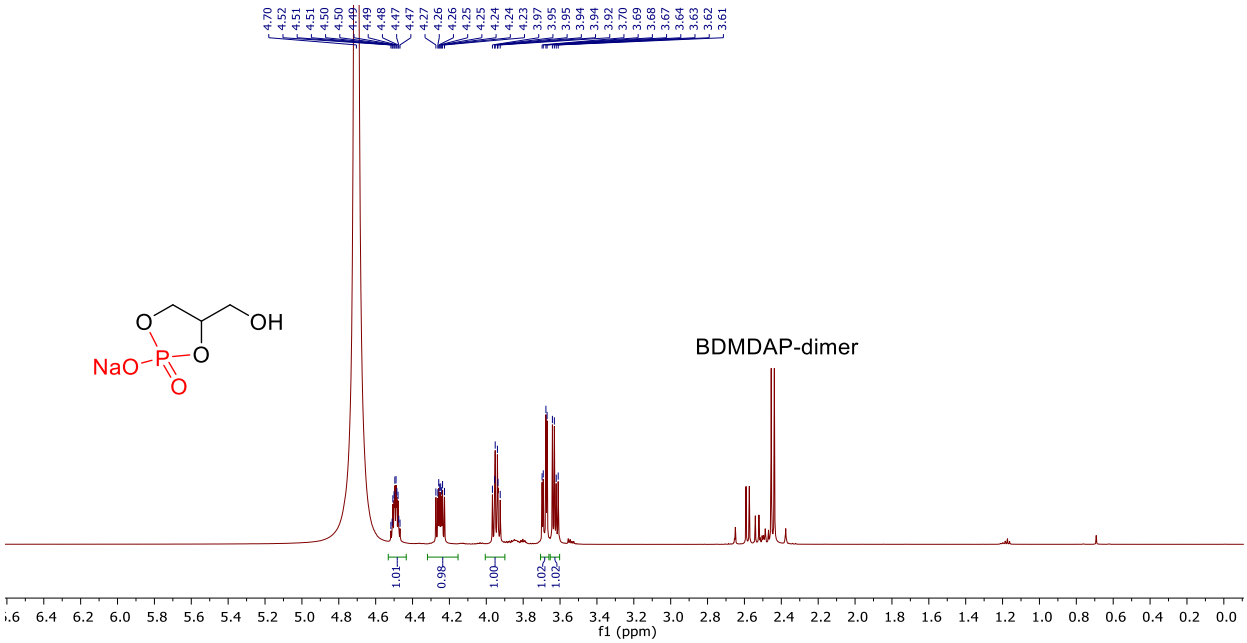
Supplementary Figure 38: ^{1}H NMR (600 MHz, D_2O) spectrum of compound **15**.



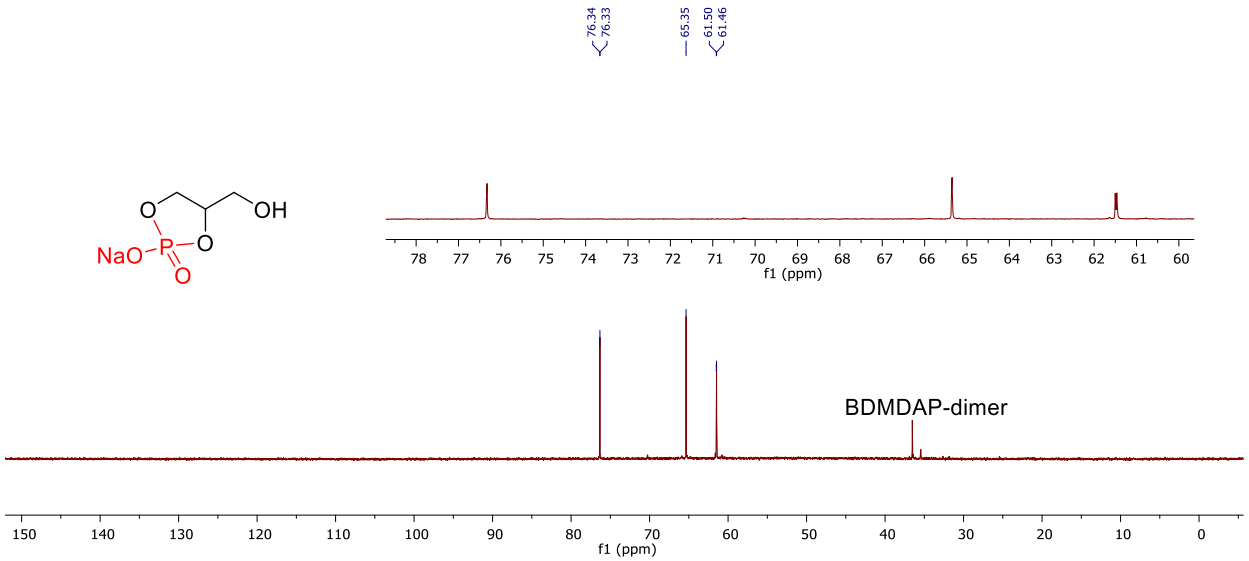
Supplementary Figure 39: ^{13}C NMR (151 MHz, D_2O) spectrum of compound **15**.



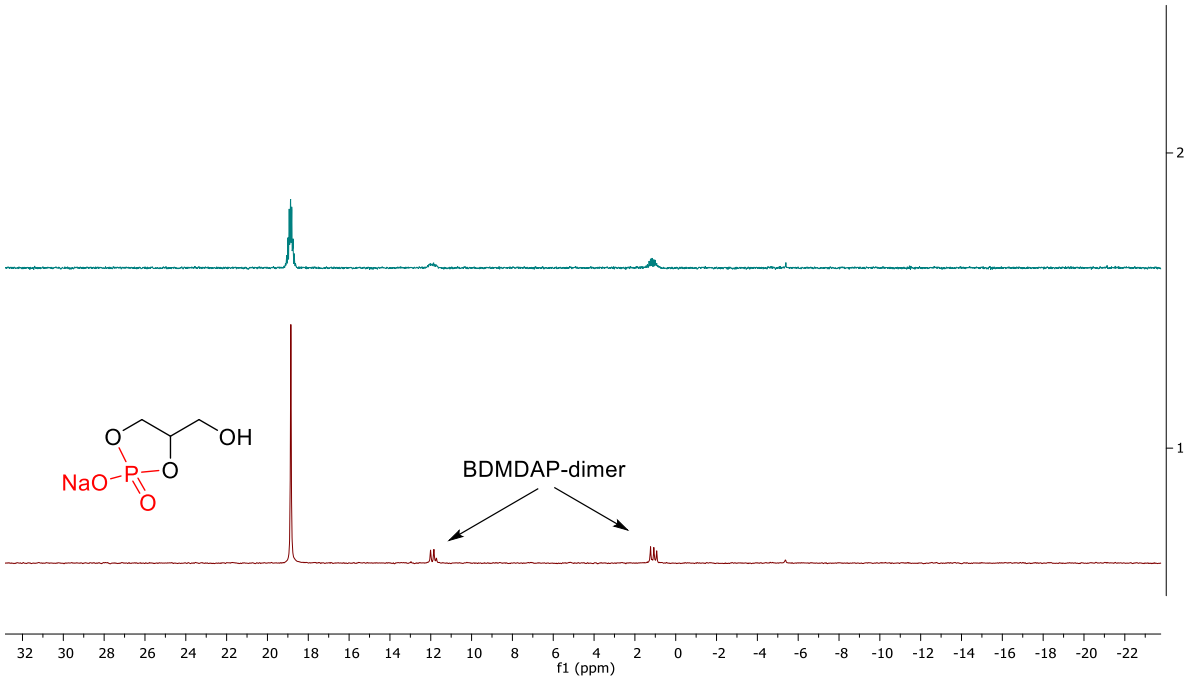
Supplementary Figure 40: ^{31}P NMR (162 MHz, D_2O) spectrum of compound **15** ({H-decoupled} = bottom spectrum, {H-coupled} = top spectrum).



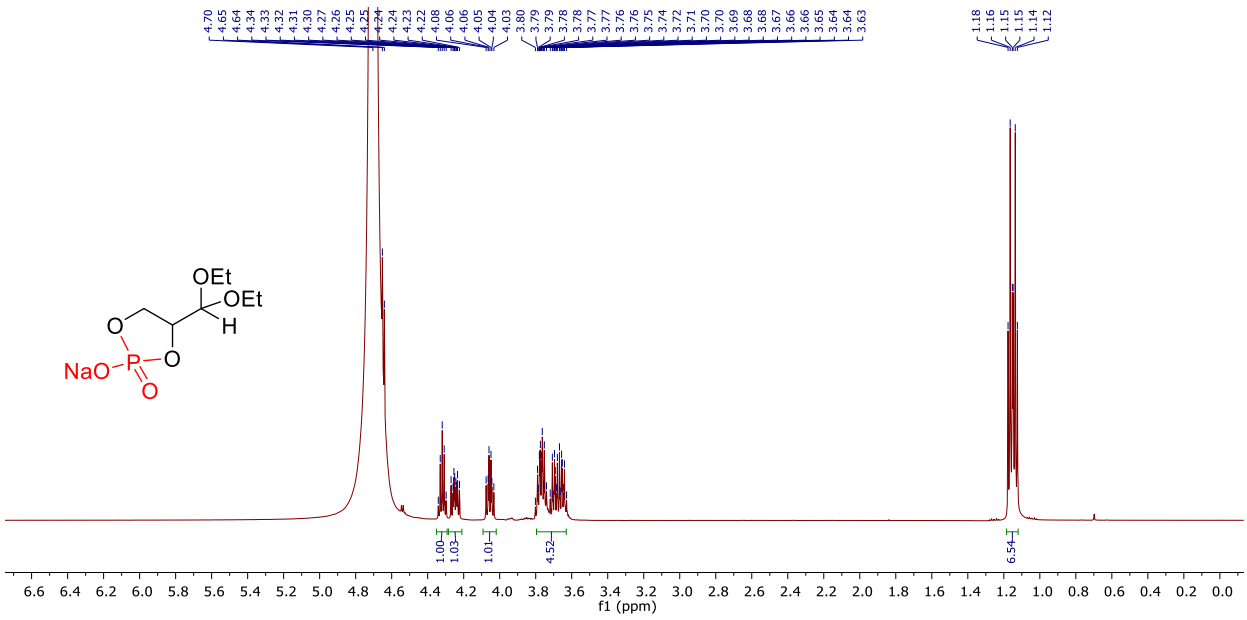
Supplementary Figure 41: ^{1}H NMR (600 MHz, D_2O) spectrum of compound **16**.



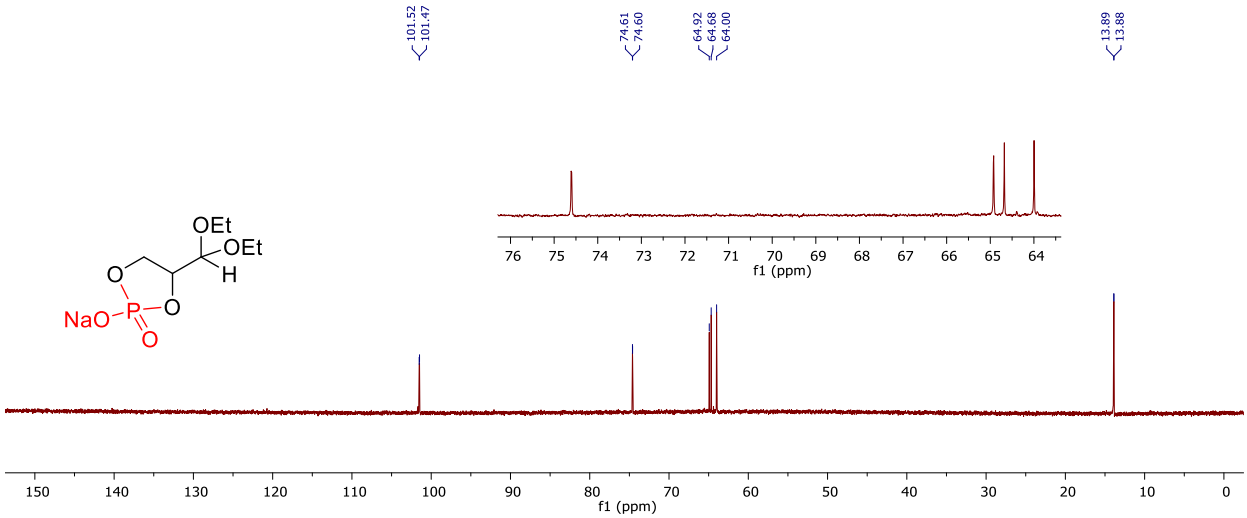
Supplementary Figure 42: ^{13}C NMR (151 MHz, D_2O) spectrum of compound **16**.



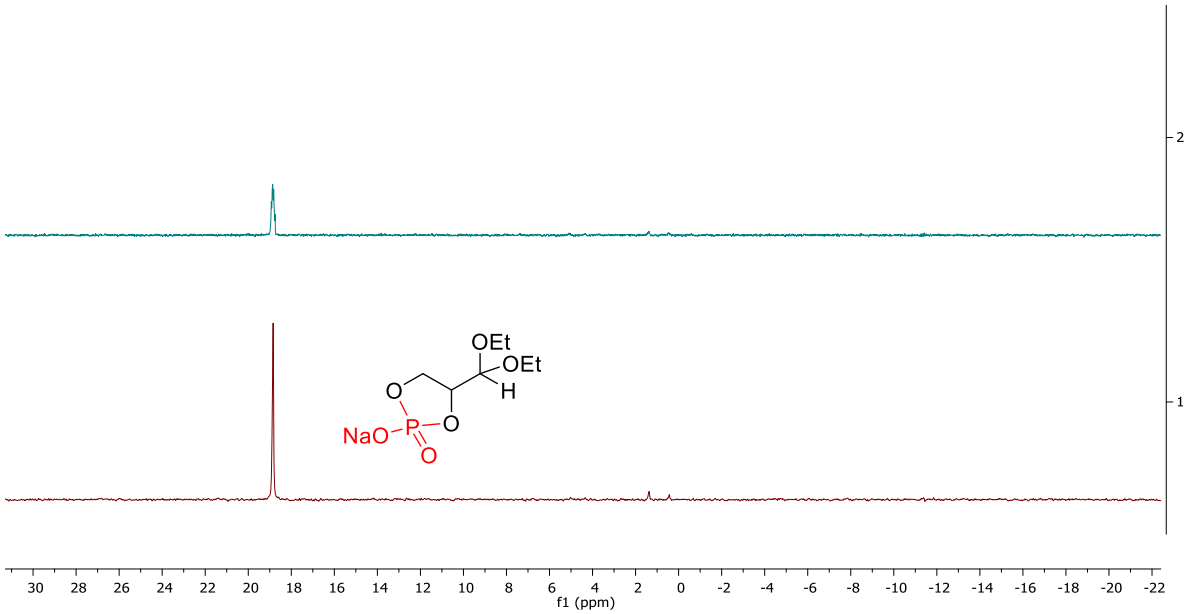
Supplementary Figure 43: ^{31}P NMR (162 MHz, D_2O) spectrum of compound **16** ({H-decoupled} = bottom spectrum, {H-coupled} = top spectrum).



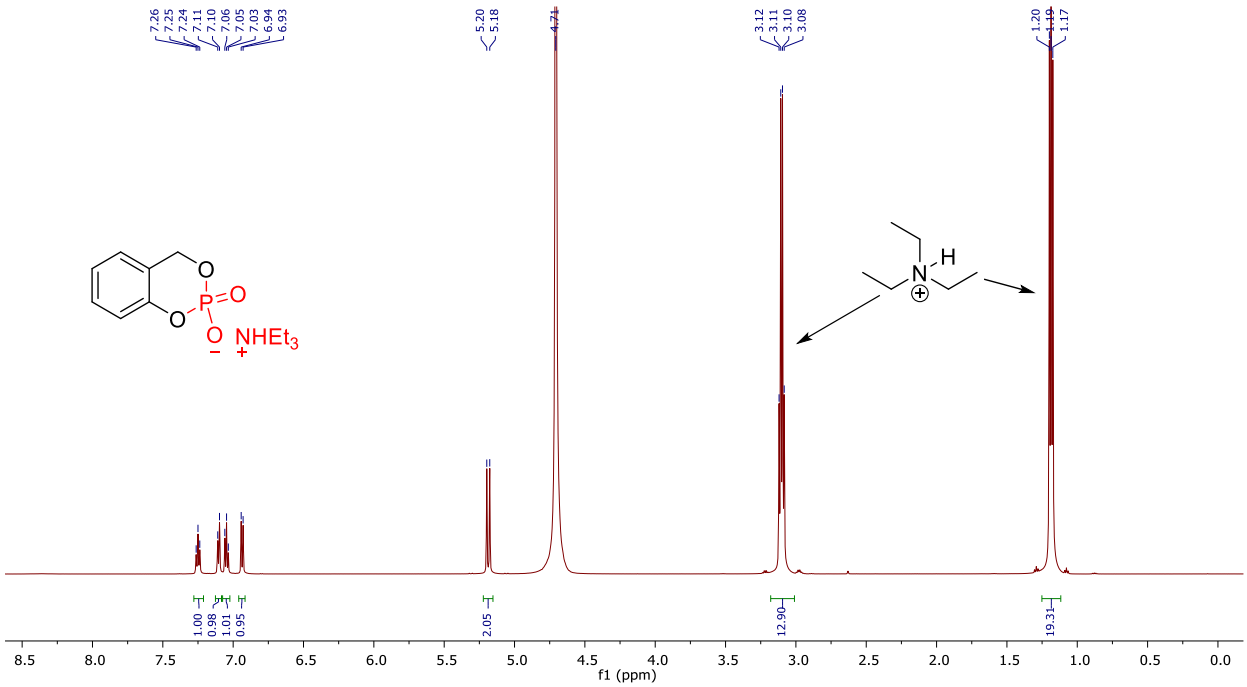
Supplementary Figure 44: ^{1}H NMR (600 MHz, D_2O) spectrum of compound **17**.



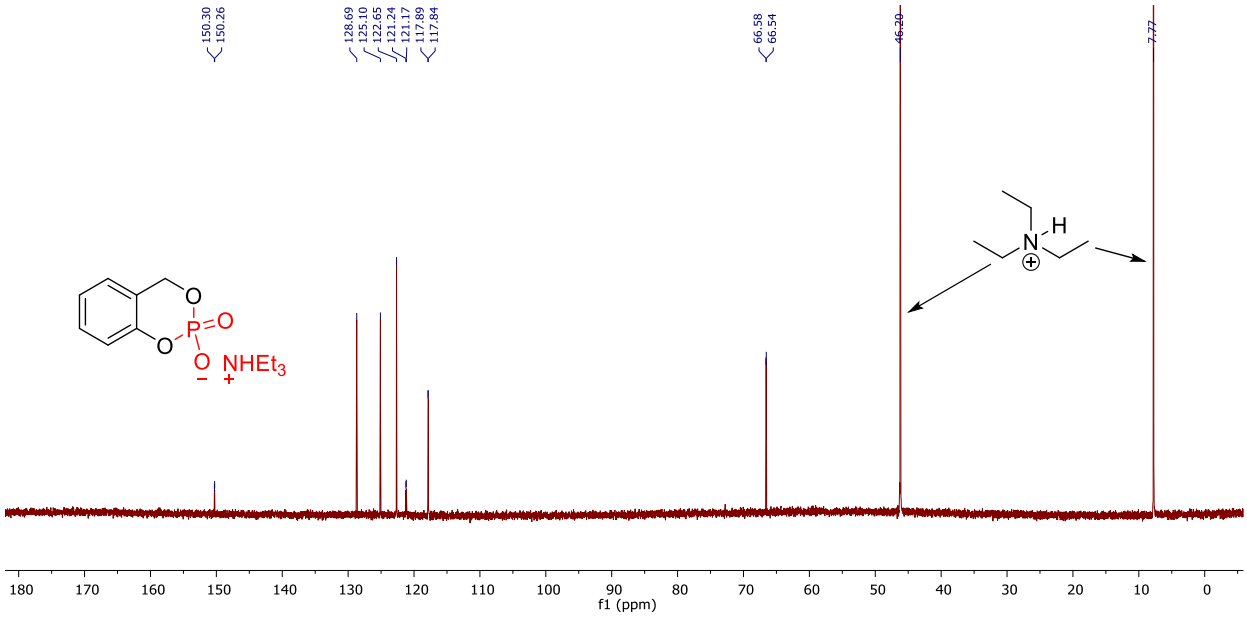
Supplementary Figure 45: ^{13}C NMR (151 MHz, D_2O) spectrum of compound **17**.



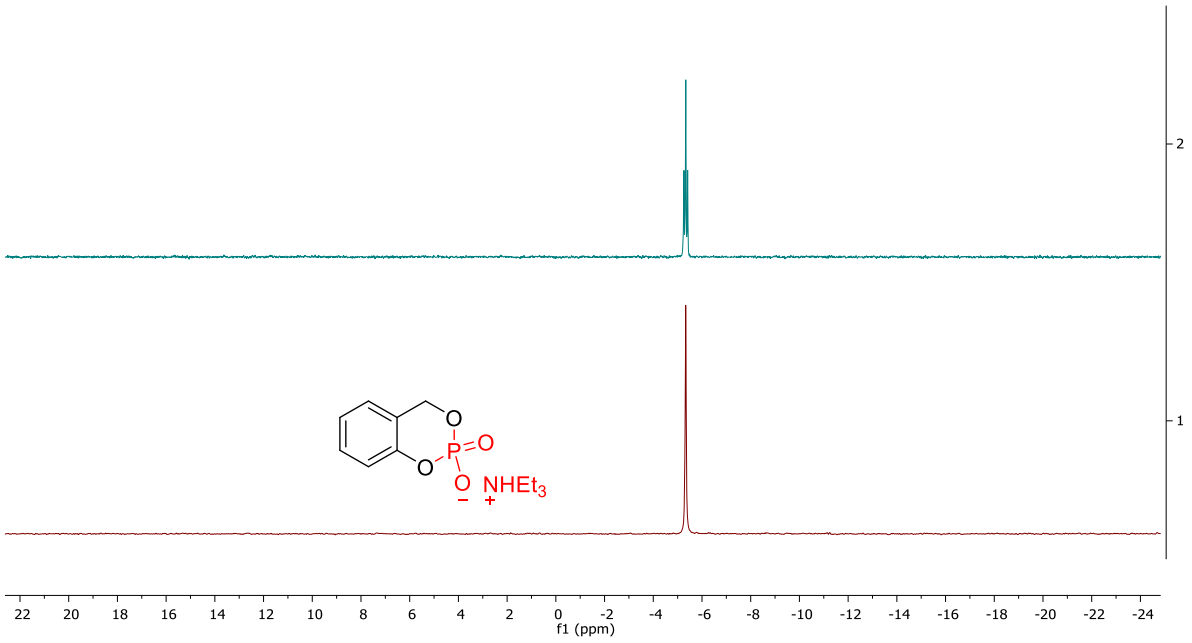
Supplementary Figure 46: ^{31}P NMR (162 MHz, D_2O) spectrum of compound **17** ({H-decoupled} = bottom spectrum, {H-coupled} = top spectrum).



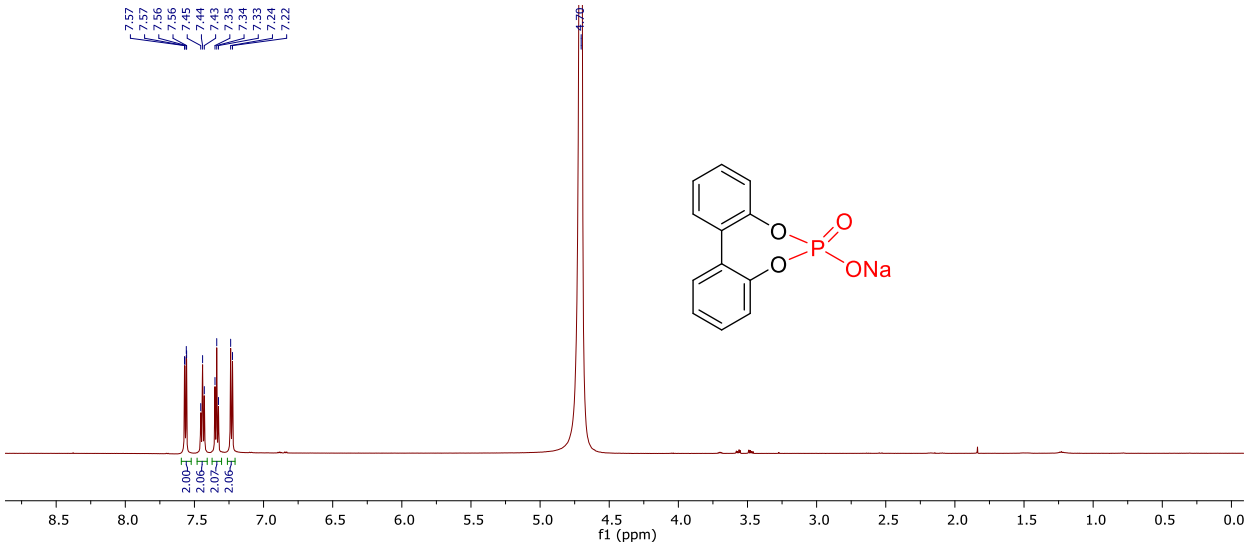
Supplementary Figure 47: ^{1}H NMR (600 MHz, D_2O) spectrum of compound **18**.



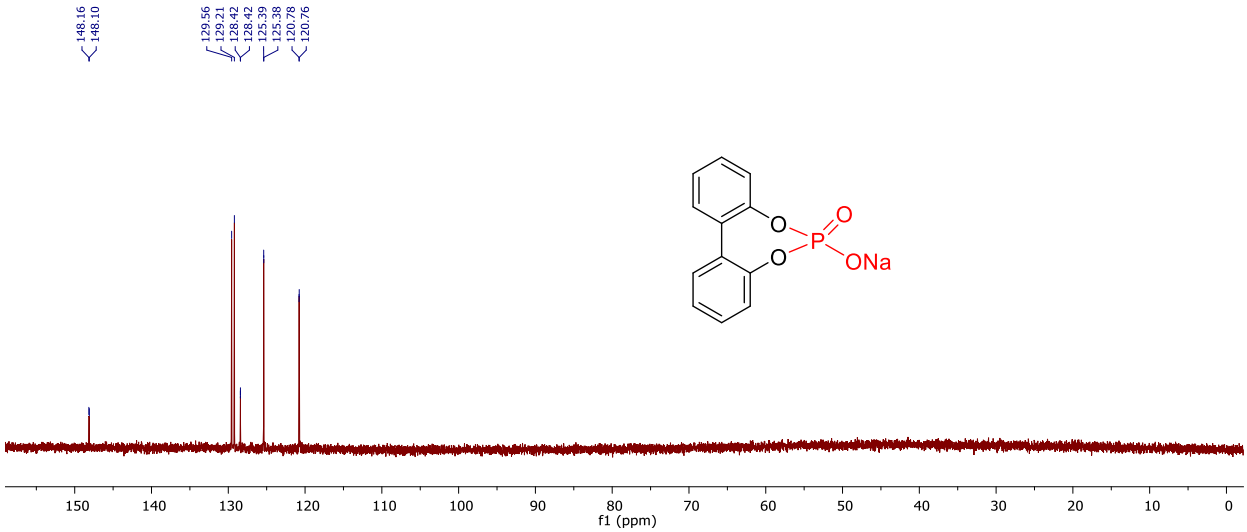
Supplementary Figure 48: ^{13}C NMR (151 MHz, D_2O) spectrum of compound **18**.



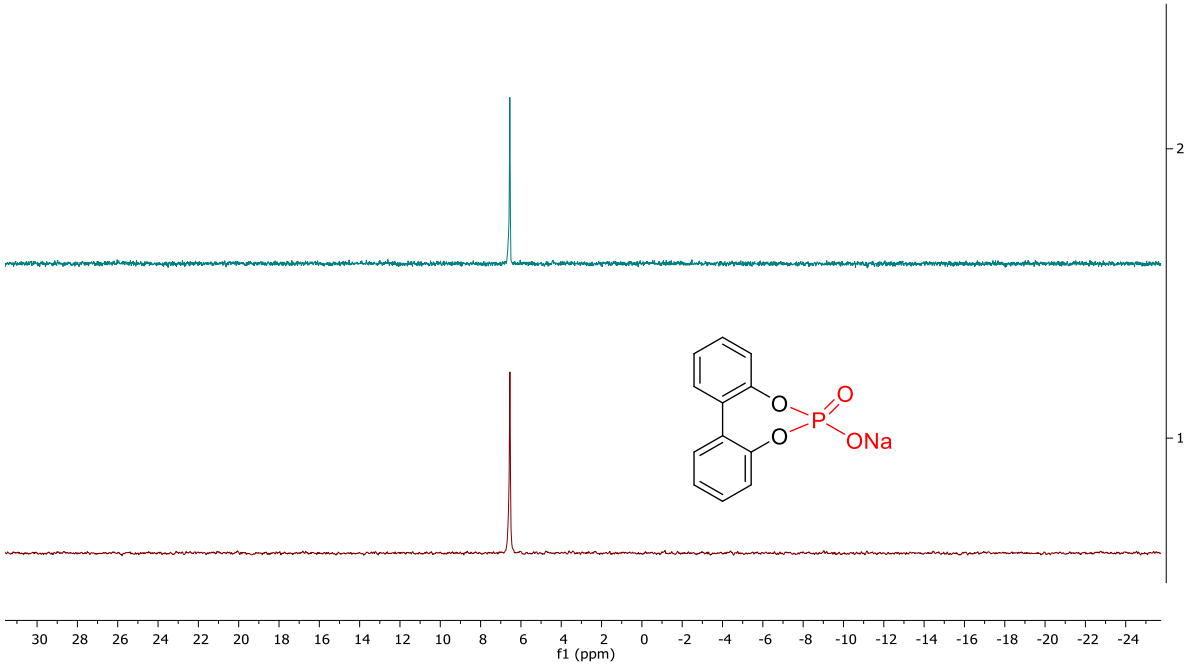
Supplementary Figure 49: ^{31}P NMR (162 MHz, D_2O) spectrum of compound **18** ({H-decoupled} = bottom spectrum, {H-coupled} = top spectrum).



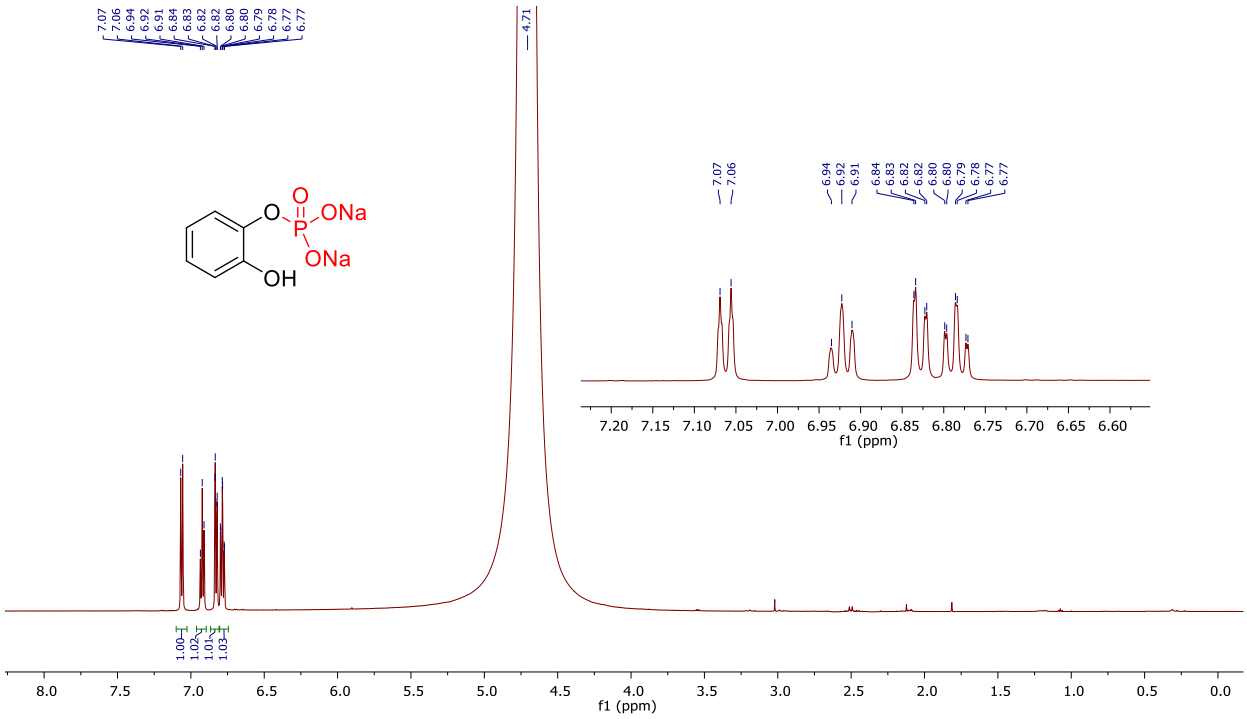
Supplementary Figure 50: ^{1}H NMR (600 MHz, D_2O) spectrum of compound **19**.



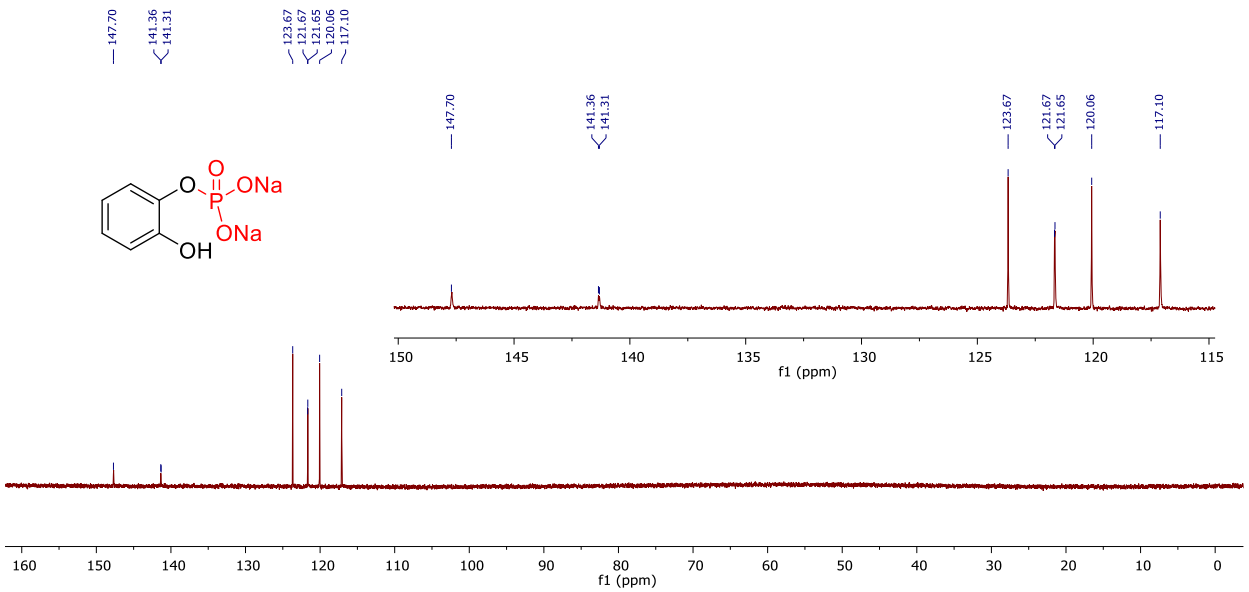
Supplementary Figure 51: ^{13}C NMR (151 MHz, D_2O) spectrum of compound **19**.



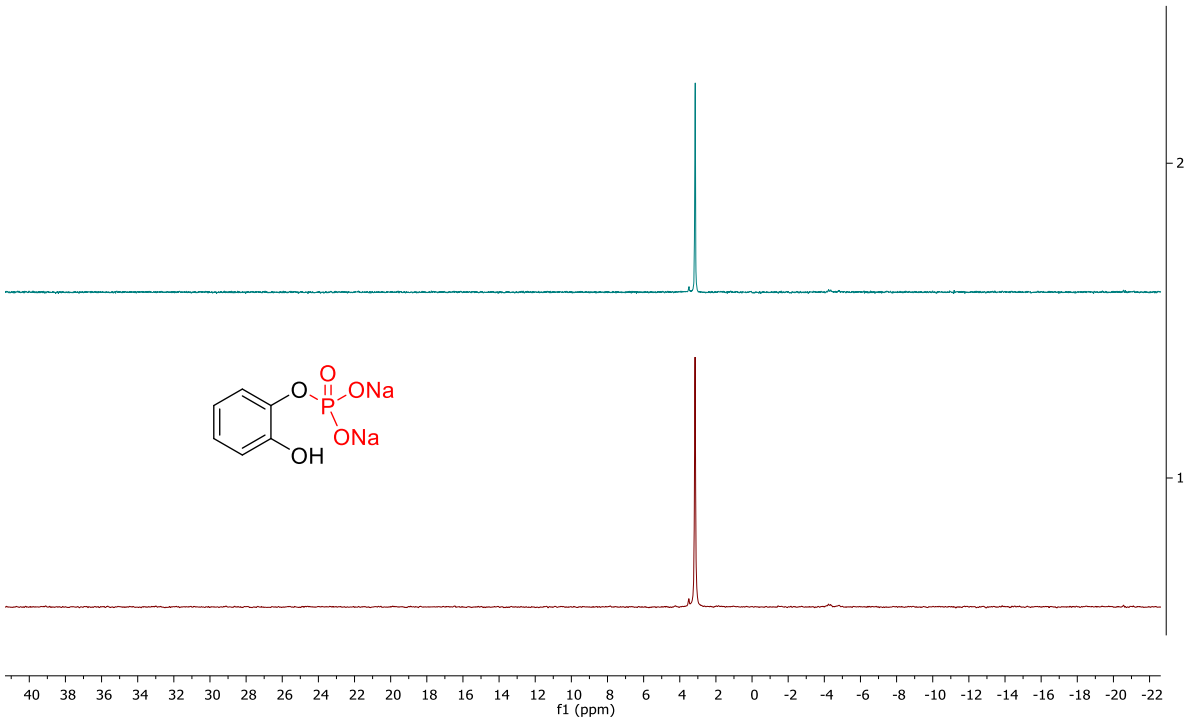
Supplementary Figure 52: ^{31}P NMR (162 MHz, D_2O) spectrum of compound **19** ({H-decoupled} = bottom spectrum, {H-coupled} = top spectrum).



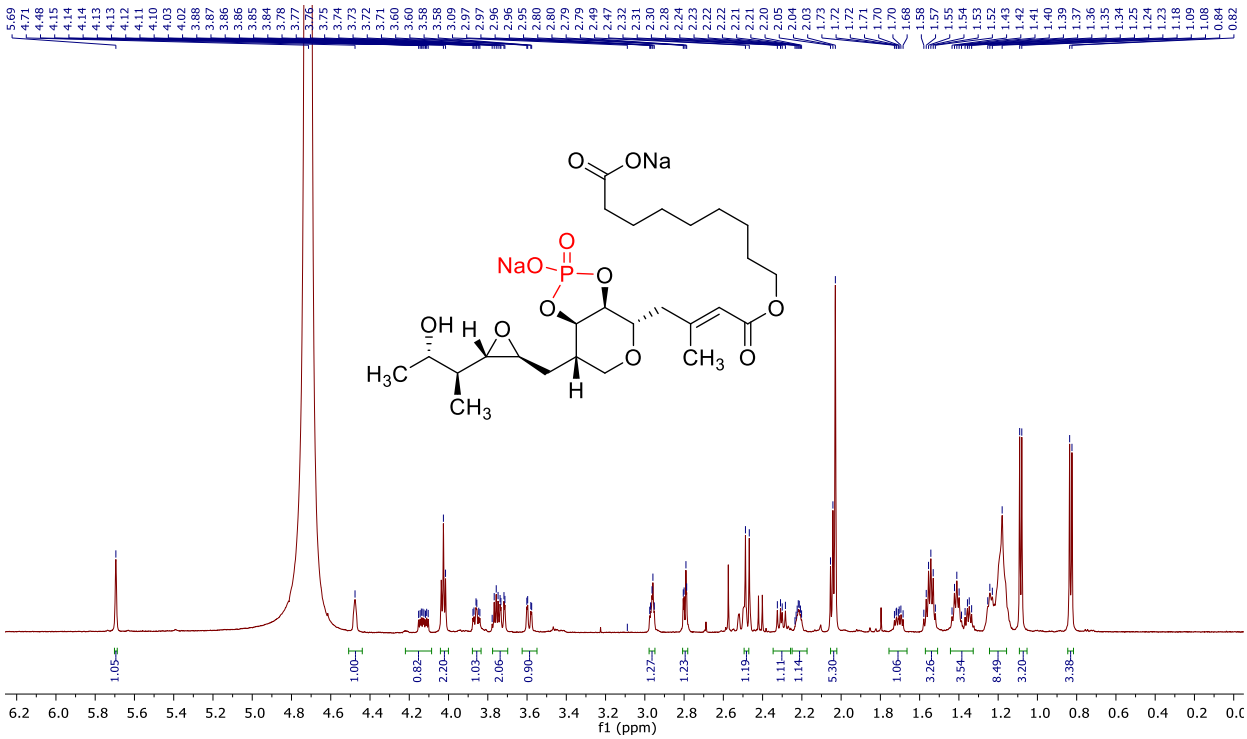
Supplementary Figure 53: ^{1}H NMR (600 MHz, D_2O) spectrum of compound **20a**.



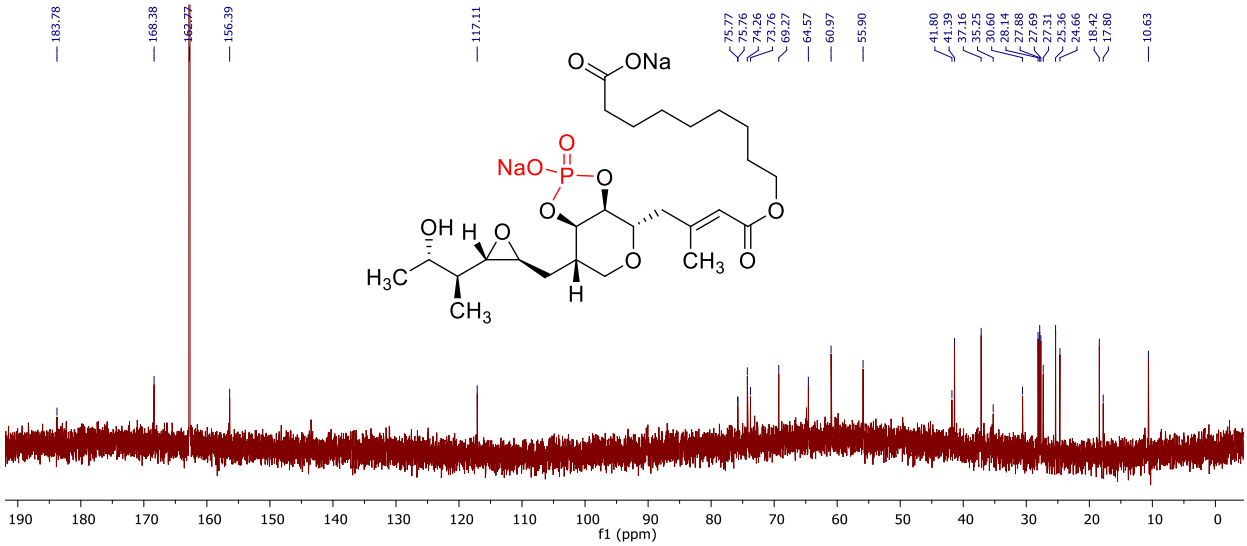
Supplementary Figure 54: ^{13}C NMR (151 MHz, D_2O) spectrum of compound **20a**.



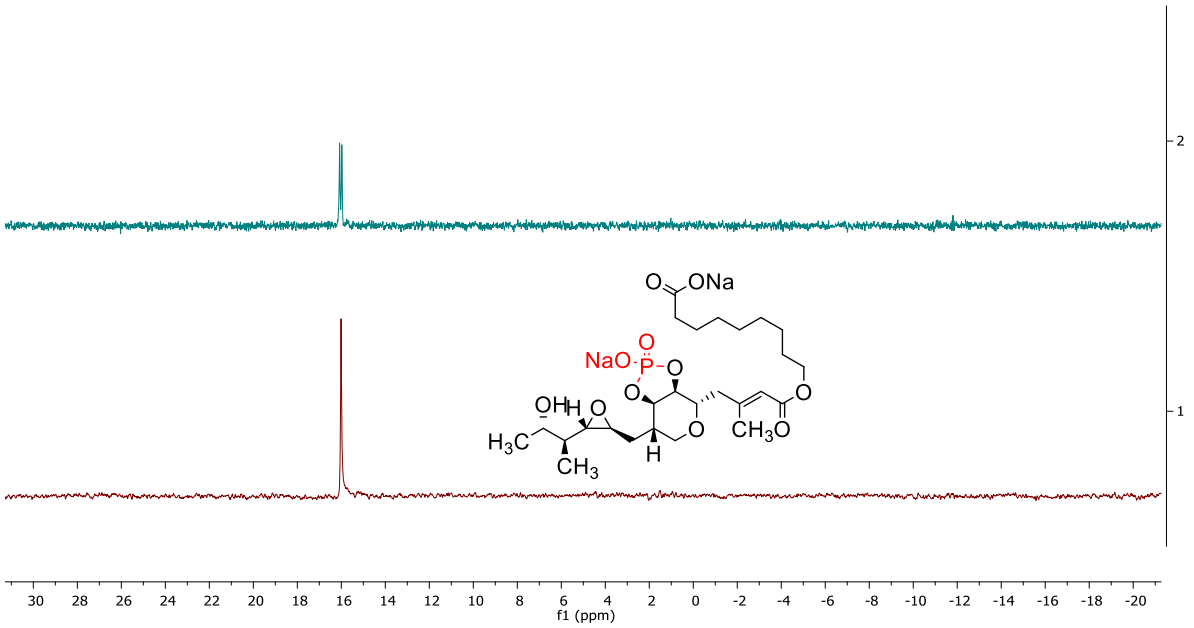
Supplementary Figure 55: ^{31}P NMR (162 MHz, D_2O) spectrum of compound **20a** ({H-decoupled} = bottom spectrum, {H-coupled} = top spectrum).



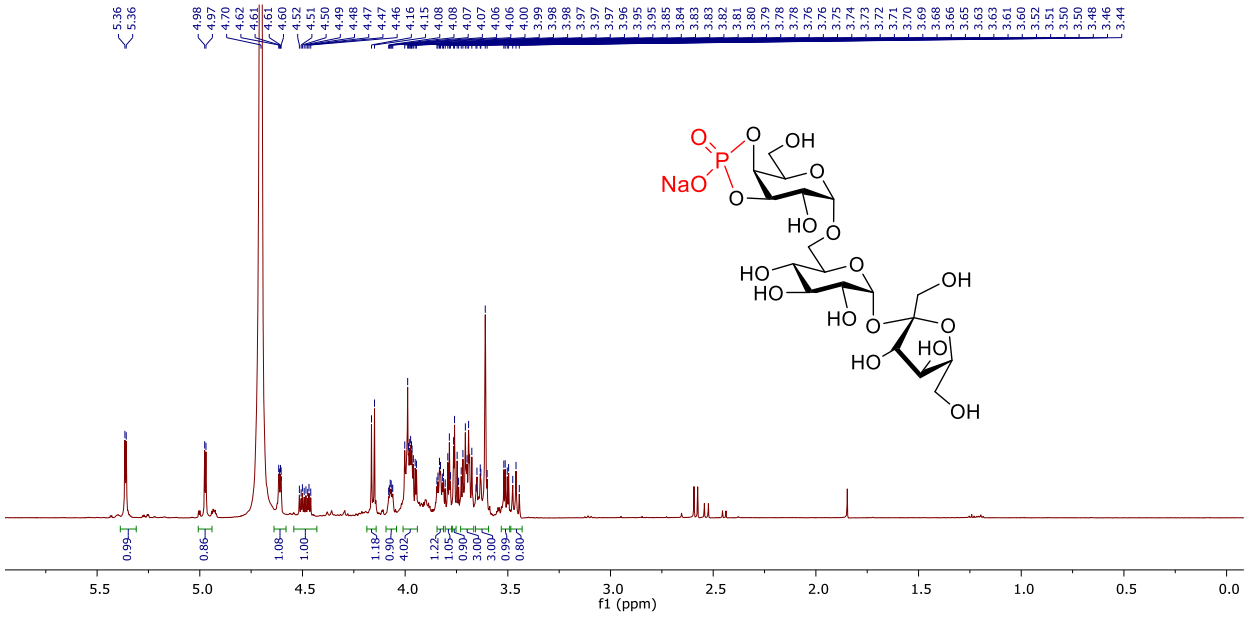
Supplementary Figure 56: ^{1}H NMR (600 MHz, D_2O) spectrum of compound **21**.



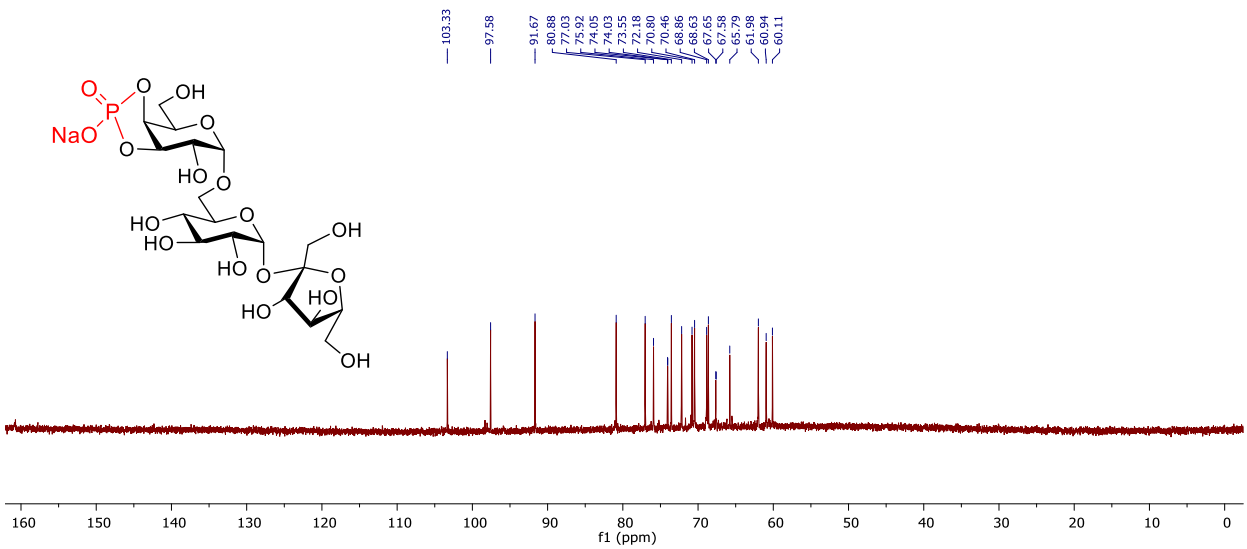
Supplementary Figure 57: ^{13}C NMR (151 MHz, D_2O) spectrum of compound **21**.



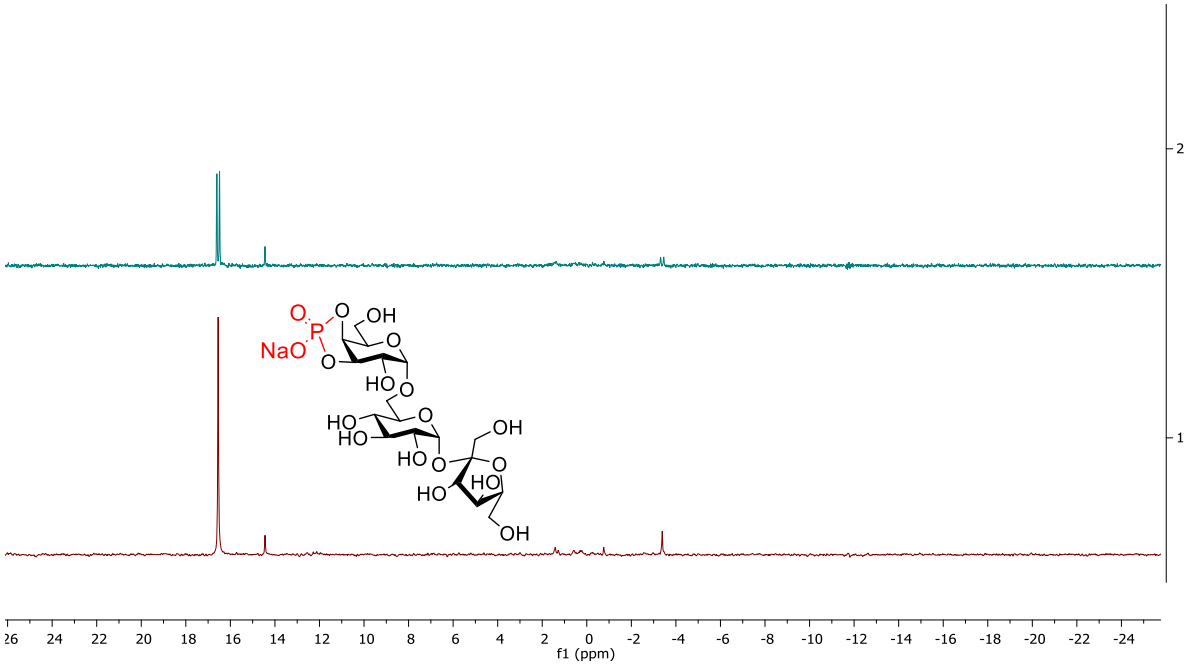
Supplementary Figure 58: ^{31}P NMR (162 MHz, D_2O) spectrum of compound **21** ({H-decoupled} = bottom spectrum, {H-coupled} = top spectrum).



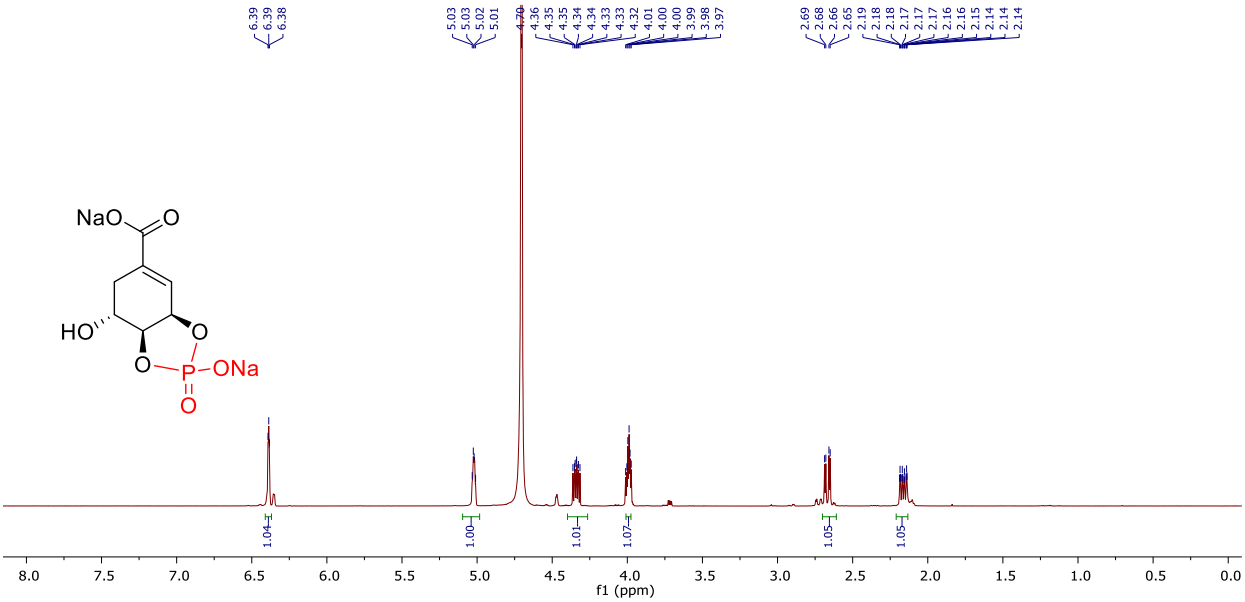
Supplementary Figure 59: ^{1}H NMR (600 MHz, D_2O) spectrum of compound **22**.



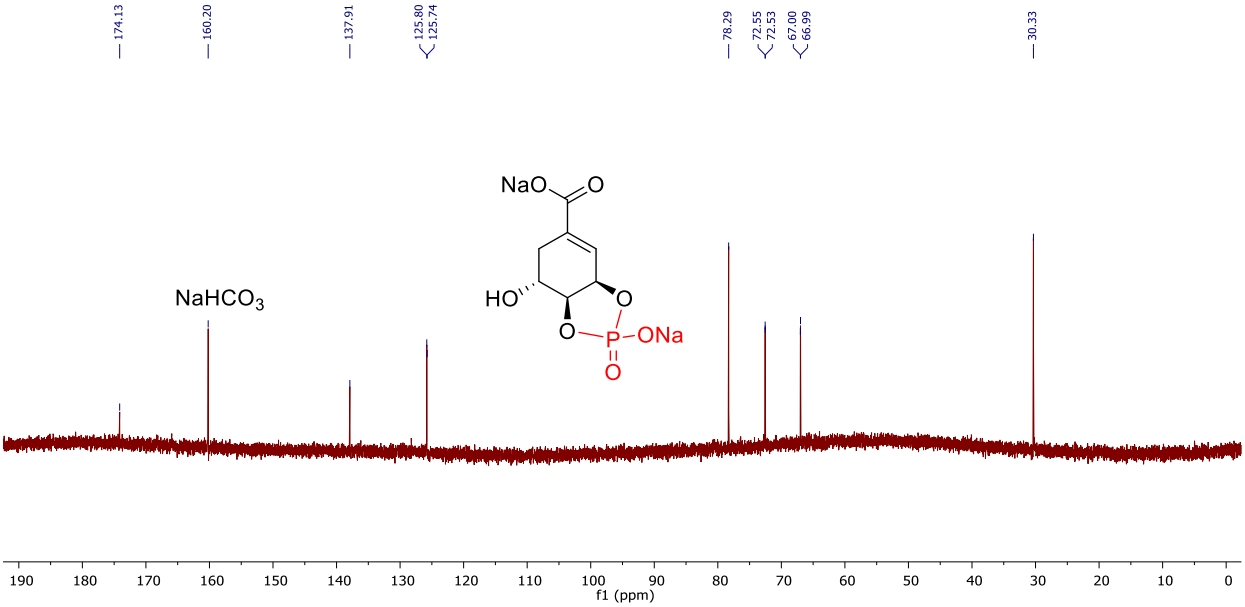
Supplementary Figure 60: ^{13}C NMR (151 MHz, D_2O) spectrum of compound **22**.



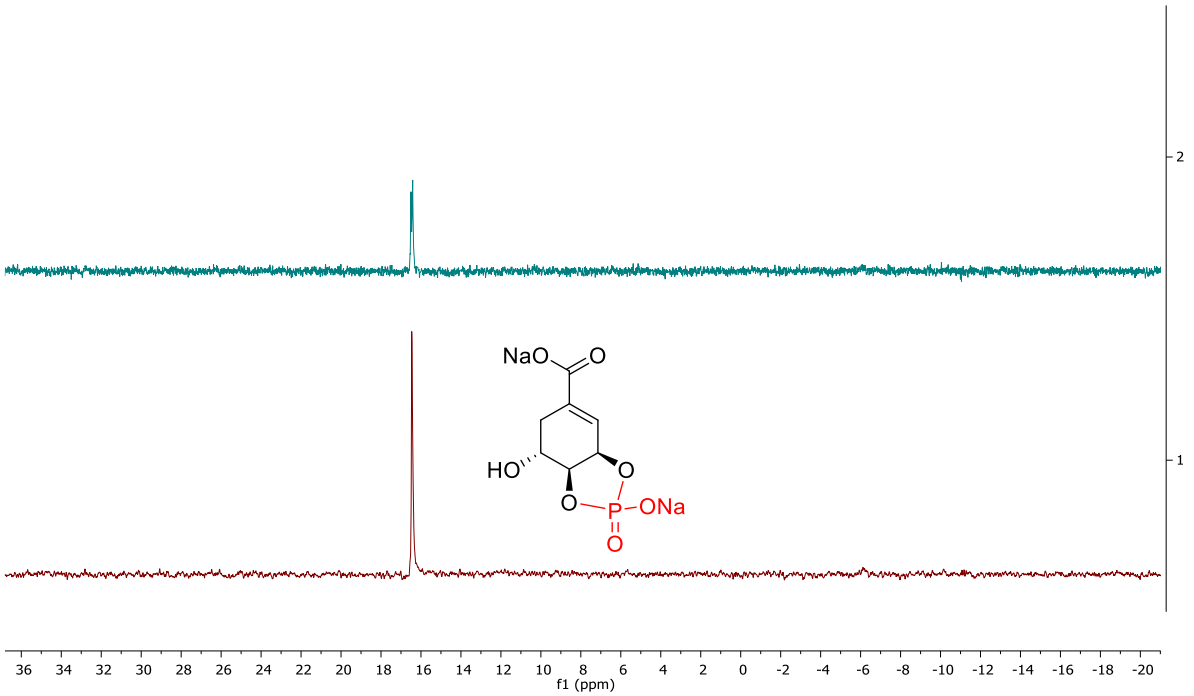
Supplementary Figure 61: ^{31}P NMR (162 MHz, D_2O) spectrum of compound **22** ({H-decoupled} = bottom spectrum, {H-coupled} = top spectrum).



Supplementary Figure 62: ^{1}H NMR (600 MHz, D_2O) spectrum of compound **23**.



Supplementary Figure 63: ^{13}C NMR (151 MHz, D_2O) spectrum of compound **23**.



Supplementary Figure 64: ^{31}P NMR (162 MHz, D_2O) spectrum of compound **23** ({H-decoupled} = bottom spectrum, {H-coupled} = top spectrum).

Supplementary References

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