Electronic Supplementary Information (ESI)

Facile syntheses of alkoxysilanated phosphorylcholines as surface modifiers: CuAAC and thiol-ene "click" reactions

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1. General information

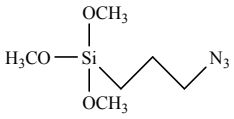
Fourier transform nuclear magnetic resonance (NMR) spectra were obtained using a Bruker AV-400 (^{1}H at 400.13 MHz, ^{13}C at 100.61 MHz, ^{29}Si at 79.49 MHz, and ^{31}P at 161.97 MHz) NMR spectrometer. XPS was carried out at the Yonsei Center for Research Facilities, Yonsei University, Korea. Elemental analyses were performed with a Perkin-Elmer 2400 CHNS/O elemental analyzer. Gas chromatography analyses were performed on an Agilent Technologies GC/MS: 6890N incorporated with 5973N Mass Selective Detector, using Flame Ionization Detector (FID) and HP 5890 II plus (HP-515 m column).

All the solvents were dried by refluxing in sodium/benzophenone system. 3-chloropropylalkoxysilanes were purchased from Sigma-Aldrich and Gelest, and used with no further purification. 3-azidopropylsilanes (**1a-1d**) were synthesized using reported method.[20] 3-mercaptopropylsilanes (**1e-1g**) were purchased from Sigma-Aldrich. **1h** was synthesized from **1f** according to reported method.[22] PPC and APC were prepared according to our reported work.[12,29]

2. Experimental section

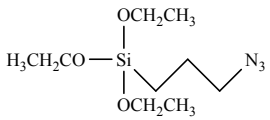
2.1 Typical procedure for synthesis of 3-azidopropylaloxysilane (1a-1d)

Into a 50 mL Schlenk flask, 3-chloropropylalkoxysilane (10 mmol) and NaN_3 (20 mmol) were placed under N_2. Then, DMF (20 mL) was added. After stirring at 75-100 ^oC for 12-16 h, the mixture was filtrated and handled in a low pressure to remove DMF. Then, the residue was distilled in a vacuum to obtain **1a-1b** as a colorless liquid in yields of 46-68%.



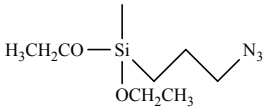
(3-azidopropyl)trimethoxysilane
1a

The reaction was carried out at 100 ^oC for 14 h, **1a** was synthesized obtained as a colorless liquid in a yield of 68%. bp. 91^oC, 10 mmHg. δ_H (400 MHz; $CDCl_3$) 3.48 (9H, s, CH_3), 3.15-3.19 (2H, t, CH_2N_3), 1.57-1.63 (2H, q, $CH_2CH_2N_3$), 0.58-0.62 (2H, t, $SiCH_2$). δ_C (100 MHz; $CDCl_3$) 53.8, 50.6, 22.56, 6.40. GC/MS: *m/z* 162.1 (M^+-N_3, 2.3%), 145.1 (12.8), 121.0 (100), 91.0 (56.4), 59.0 (17.1) etc.



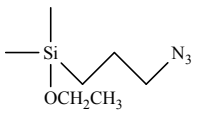
(3-azidopropyl)triethoxysilane
1b

The reaction was carried out at 100 °C for 16 h, **1b** was obtained as a colorless liquid in a yield of 62%. bp. 58-60 °C, 0.2 torr. δ_H (400 MHz; $CDCl_3$) 3.79-3.85 (6H, q, OCH_2), 3.24-3.28 (2H, t, CH_2N_3), 1.67-1.75 (2H, m, $CH_2CH_2N_3$), 1.23-1.26 (9H, t, CH_3), 0.62-0.63 (2H, t, $SiCH_2$). δ_C (100 MHz; $CDCl_3$) 58.6, 54.0, 32.8, 18.4, 7.84. GC/MS: *m/z* 202.1 (M^+-N_3, 2.0%), 163.1 (100), 119.1 (60.1), 79.0 (39.6), 63.0 (24.2) etc.



(3-azidopropyl)diethoxy(methyl)silane
1c

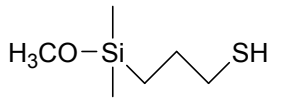
The reaction was carried out at 85 °C for 12 h, **1c** was obtained as a colorless liquid in a yield of 56%. bp. 40 °C, 0.18 torr. δ_H (400 MHz; $CDCl_3$) 3.69-3.74 (4H, q, OCH_2), 3.18-3.22 (2H, t, CH_2N_3), 1.58-1.66 (2H, m, $SiCH_2CH_2$), 1.15-1.18 (6H, t, CH_3), 0.58-0.62 (2H, t, $SiCH_2$), 0.08 (3H, s, $SiCH_3$). δ_C (100 MHz; $CDCl_3$) 57.9, 53.8, 22.5, 18.1, 10.9, 5.17. GC/MS: *m/z* 174.2 (M^+-N_3, 2.3%), 146.1 (8.0), 133.2 (100), 105.1 (20.0), 77.1 (34.3) etc.



(3-azidopropyl)(ethoxy)dimethylsilane
1d

The reaction was carried out at 80 °C for 12 h, **1d** was obtained as a colorless liquid in a yield of 46%. bp. 94-96 °C, 30 mmHg. δ_H (400 MHz; $CDCl_3$) 3.59-3.64 (2H, q, CH_2N_3), 3.18-3.21 (2H, t, CH_2O), 1.58-1.62 (2H, q, $SiCH_2CH_2$), 1.12-1.15 (3H, t, CH_3), 0.56-0.61 (2H, t, $SiCH_2$), 0.07 (3H, s, CH_3). δ_C (100 MHz; $CDCl_3$) 58.3, 54.3, 23.1, 18.6, 13.6, 0.03. GC/MS: *m/z* 144.2 (M^+-N_3, 2.1%), 116.1 (16.4), 103.2 (100), 75.1 (45.8), 59.1 (21.3) etc.

2.2 Synthesis of 1h

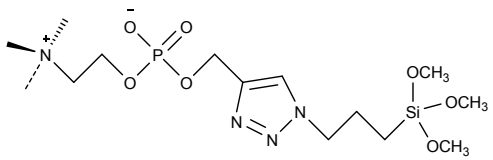


3-mercaptopropylmethoxydimethylsialne
1h

1h was synthesized from **1f** according to reported work.[30] δ_H (400 MHz; $CDCl_3$) 3.25 (3H, s, OCH_3), 2.26 (2H, q, SCH_2), 1.51 (2H, m, $SiCH_2CH_2$), 1.24 (1H, t, SH), 0.48 (2H, m, $SiCH_2$), 0.04(6H, s, $SiCH_3$). GC/MS: *m/z* 164.2 (M, 1.2%) 149.1 (27.1), 132.1 (61.7), 89.2 (100), 59.2 (40) etc.

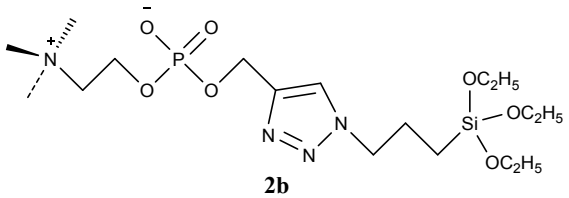
2.3 Typical procedure for the synthesis of triazole-bridged alkoxysilanes (2a-2d)

Equimolar amounts of 3-azidopropylalkoxysilane and PPC (1 mmol) were mixed in the presence of CuI/DIPEA (2 mmol/4 mmol). Then, these reactants were dissolved in ethanol under Ar. Reactions could be run in ethanol and proceed smoothly at 60°C for 12 h. To purify the final products, the Cu(I) catalyst was filtrated under N_2. After removing the solvent at reduced pressure, the residue was washed several times using anhydrous hexane and dried in a vacuum. Finally, the targeted products were obtained as yellow powders in yields of 90-92%.



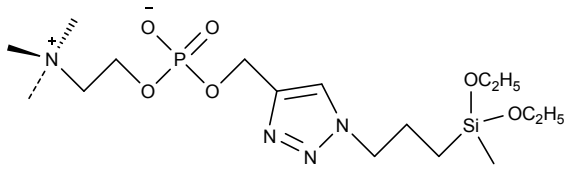
2a

2a was obtained as a yellow powder in a yield of 90%. δ_H (400 MHz; CD_3OD) 7.92 (1H, s, CHN_3), 5.02-5.04 (2H, d, OCH_2C=), 4.42-4.44 (2H, t, CH_2CH_2N), 4.32 (2H, s, N_3CH_2), 3.50-3.61 (11H, m, OCH_3, CH_2CH_2N), 3.29 (9H, s, NCH_3), 1.90-1.96 (2H, m, $SiCH_2CH_2$), 0.58-0.65 (2H, t, $SiCH_2$). δ_C (100 MHz; CD_3OD) 141.7, 127.2, 71.2, 66.1, 58.7, 55.0, 54.5, 49.6, 19.4, 8.17. δ_P (161 MHz; CD_3OD) -0.56.



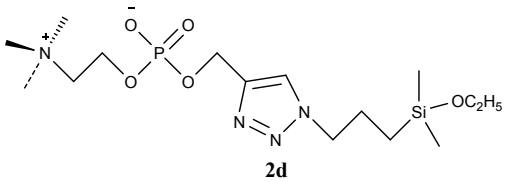
2b

2b was obtained as a yellow powder in a yield of 91%. δ_H (400 MHz; CD_3OD) 8.00 (1H, s, CHN_3), 5.06-5.08 (2H, d, OCH_2C=), 4.44-4.47 (2H, t, CH_2CH_2N), 4.33 (2H, s, N_3CH_2), 3.87-3.93 (6H, q, $SiOCH_2$), 3.68-3.70 (2H, t, CH_2CH_2N), 3.30 (9H, s, NCH_3), 2.02-2.13 (2H, m, $SiCH_2CH_2$), 1.28-1.31 (9H, t, $SiOCH_2CH_3$), 0.63-0.70 (2H, t, $SiCH_2$). δ_C (100 MHz; CD_3OD) 146.2, 125.3, 67.5, 60.4, 59.8, 58.3, 54.7, 53.6, 25.3, 18.7, 8.29. δ_{Si} (79 MHz; CD_3OD) -46.54. δ_P (161 MHz; CD_3OD) -0.62.



2c

2c was obtained as a yellow powder in a yield of 91%. δ_H (400 MHz; CD_3OD) 7.96 (1H, s, CHN_3), 4.91-4.93 (2H, d, OCH_2C=), 4.32-4.34 (2H, t, CH_2CH_2N), 4.21 (2H, s, N_3CH_2), 3.66-3.69 (4H, q, $SiOCH_2$), 3.51-3.58 (2H, t, CH_2CH_2N), 3.16 (9H, s, NCH_3), 1.87-1.89 (2H, m, $SiCH_2CH_2$), 1.05-1.07 (6H, t, $SiOCH_2CH_3$), 0.48-0.52 (2H, t, $SiCH_2$), 0.06 (3H, s, $SiCH_3$). δ_C (100 MHz; CD_3OD) 145.5, 124.8, 67.0, 59.3, 57.8, 54.2, 52.9, 51.0, 23.2, 17.9, 10.2, 0.62. δ_P (161 MHz; CD_3OD) -0.39.



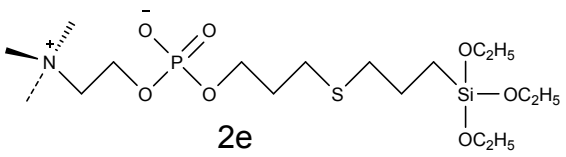
2d

2d was obtained as a yellow powder in a yield of 92%. δ_H (400 MHz; CD_3OD) 7.92 (1H, s, CHN_3), 4.86-4.88 (2H, d, OCH_2C=), 4.25-4.27 (2H, t, CH_2CH_2N), 4.15 (2H, s, N_3CH_2), 3.53 (4H, br s, $SiOCH_2$, CH_2CH_2N), 3.11 (9H, s, NCH_3), 1.80 (2H, m, $SiCH_2CH_2$), 1.04-1.06 (3H, t, $SiOCH_2CH_3$), 0.37-0.43 (2H, t, $SiCH_2$), 0.02 (6H, s, $SiCH_3$). δ_C (100 MHz; CD_3OD) 146.0, 125.5, 67.6, 65.3, 60.5, 59.5, 57.8, 54.6, 25.9,

19.6, 14.0, 0.44. δ_P (161 MHz; CD_3OD) -0.24.

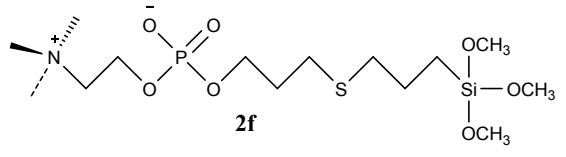
2.4 Typical procedure for the synthesis of 2e-2h

A slight excess of 3-mercaptopropyl alkoxysilane (**1e-1h**, 1.10 mmol) and APC (1 mmol) were dissolved in 2 mL of EtOH in the presence of 2 mol% benzophenone. The reactions proceeded for 15 min at room temperature under a 300 nm UV lamp. After removing the solvents at reduced pressure, the crude product residue was washed with hexane to remove excess 3-mercaptopropyl alkoxysilanes and benzophenone. The final products precipitated from hexane as light yellow powders, and then the precipitation was dried in a vacuum. (**2e-2h**) were obtained in quantitative yields.



2e

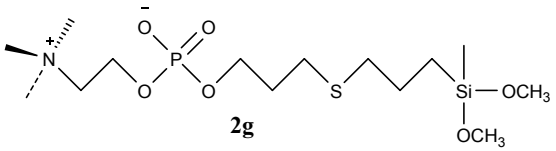
2e was obtained as a yellow powder. δ_H (400 MHz; CD_3OD) 4.19 (2H, br s, NCH_2CH_2), 3.88-3.91 (2H, t, $POCH_2$), 3.74-3.77 (6H, q, $SiOCH_2$), 3.56-3.58 (2H, t, NCH_2), 3.16 (9H, s, NCH_3), 2.45-2.56 (4H, tt, CH_2SCH_2), 1.79-1.85 (2H, m, $POCH_2CH_2$), 1.57-1.63 (2H, m, $SiCH_2CH_2$), 1.14 (9H, s, CH_3), 0.68-0.71 (2H, t, $SiCH_2$). δ_C (100 MHz; CD_3OD) 67.8, 65.7, 59.8, 58.6, 55.0, 36.1, 32.1, 29.3, 24.6, 19.0, 18.7. δ_P (161 MHz; CD_3OD) -0.21.



2f

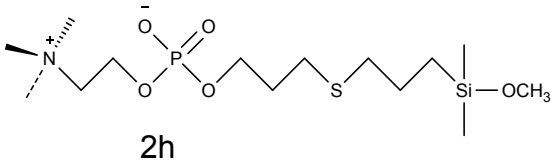
2f was obtained as a yellow powder. δ_H (400 MHz; CD_3OD) 4.13 (2H, br s, NCH_2CH_2), 3.82-3.88 (2 H, m, $POCH_2$), 3.49-3.65 (2H, t, NCH_2; 9H, s, OCH_3), 3.11 (9H, s, NCH_3), 2.40-2.52 (4H, tt, CH_2SCH_2), 1.74-1.77 (2H, t, $POCH_2CH_2$), 1.59 (2H, s, $SiCH_2CH_2$), 0.57-0.61 (2H, t, $SiCH_2$). δ_C (100 MHz; CD_3OD) 67.7, 65.5, 60.6, 54.9,

51.2, 36.2, 31.9, 29.1, 24.7, 17.8. δ_P (161 MHz; CD_3OD) -0.16.



2g

2g was obtained as a yellow powder. δ_H (400 MHz; CD_3OD) 4.20 (2H, br s, NCH_2CH_2), 3.89-3.91 (2 H, m, $POCH_2$), 3.58-3.72 (2H, t, NCH_2; 6H, s, OCH_3), 3.16 (9H, s, NCH_3), 2.48-2.56 (4H, tt, CH_2SCH_2), 1.83-1.85 (2H, t, $POCH_2CH_2$), 1.58-1.60 (2H, s, $SiCH_2CH_2$), 0.86-0.89 (2H, t, $SiCH_2$), 0.02 (3H, s, $SiCH_3$). δ_C (100 MHz; CD_3OD) 67.6, 65.4, 60.4, 54.8, 48.1, 36.2, 32.0, 29.1, 24.7, 17.5, 0.15. δ_P (161 MHz; CD_3OD) -0.10.



2h

2h was obtained as a yellow powder. δ_H (400 MHz; CD_3OD) 4.33-4.34 (2H, br s, NCH_2CH_2), 3.88-3.93 (2H, m, $POCH_2$), 3.70 (2H, t, NCH_2), 3.58 (3H, s, OCH_3), 3.17 (9H, s, NCH_3), 2.43-2.59 (4H, tt, CH_2SCH_2), 1.82-1.85 (2H, t, $POCH_2CH_2$), 1.60-1.62 (2H, s, $SiCH_2CH_2$), 0.59-0.63 (2H, t, $SiCH_2$), 0.02-0.04 (6H, s, $SiCH_3$). δ_C (100 MHz; CD_3OD) 67.4, 65.2, 60.1, 54.2, 47.9, 36.0, 31.5, 28.6, 24.0, 17.0, 0.09. δ_P (161 MHz; CD_3OD) -0.06

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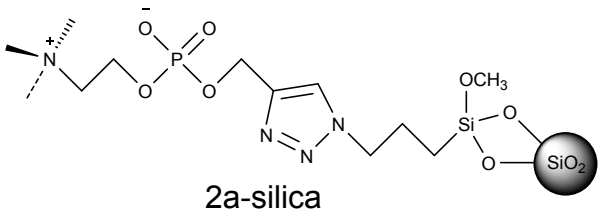
2.5 Typical procedure for the surface modification of silica beads

2.5.1 Typical procedure for the surface modification of silica beads using triazole-bridged alkoxysilanated PC (2a-2d)

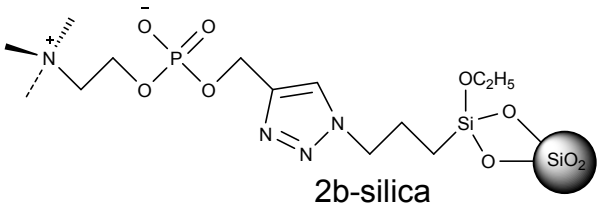
A mixture consisting of triazole-bridged silanated PC (1 mmol) of (**2a-2d**), 400 mg of amorphous silica balls (Aldrich, USA, 10 μm, 300 m^2g^{-1}) and 20 mL of IPA/toluene (V/V = 1:1) was placed in a 50 mL high pressure vessel and heated at 90 ^oC for 24 h. After cooling to room temperature, the resulted silica was filtered and washed with

methanol and toluene, and dried under vacuum to yield a light yellow powder **(2a-2d)-silica.**



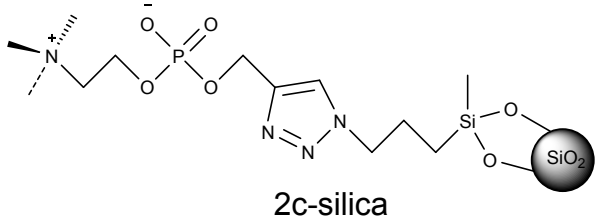
2a-silica

2a-silica was obtained as light yellow powder. Found: C, 6.0886; N, 2.4524%. The loading rate for alkoxysilanated PC was based on the N value of modified silica determined by elemental analysis. For example: calculation of the loading rate of **2a** modified silica **2a-silica** = (2.4524 × 10^{-2} g of N/1 g of compound PC-modified silica **2a-silica**) × (10^3 mmol of N/14 g of N) × (1 mmol of **2a**/4 mmol of N) = 0.44 mmol **2a**/1 g of compound PC-modified **2a-silica**.



2b-silica

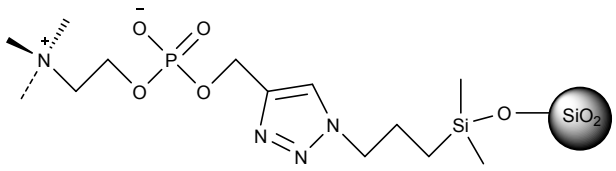
2b-silica was obtained as light yellow powder. Found: C, 5.6236; N, 2.1188%. The loading rate for alkoxysilanated PC was based on the N value of modified silica determined by elemental analysis. For example: calculation of the loading rate of **2b** modified silica **2b-silica** = (2.1188 × 10^{-2} g of N/1 g of compound PC-modified silica **2b-silica**) × (10^3 mmol of N/14 g of N) × (1 mmol of **2b**/4 mmol of N) = 0.38 mmol **2b**/1 g of compound PC-modified **2b-silica**.



2c-silica

2c-silica was obtained as light yellow powder. Found: C, 5.2442; N, 1.7159%. The

loading rate for alkoxysilanated PC was based on the N value of modified silica determined by elemental analysis. For example: calculation of the loading rate of **2c** modified silica **2c-silica** = (1.7159 × 10^{-2} g of N/1 g of compound PC-modified silica **2c-silica**) × (10^3 mmol of N/14 g of N) × (1 mmol of **2c**/4 mmol of N) = 0.31 mmol **2c**/1 g of compound PC-modified **2c-silica**.

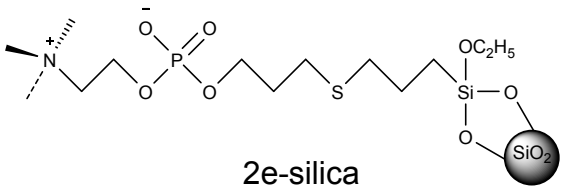


2d-silica

2d-silica was obtained as light yellow powder. Found: C, 5.1701; N, 1.8836%. The loading rate for alkoxysilanated PC was based on the N value of modified silica determined by elemental analysis. For example: calculation of the loading rate of **2d** modified silica **2d-silica** = (1.8836 × 10^{-2} g of N/1 g of compound PC-modified silica **2d-silica**) × (10^3 mmol of N/14 g of N) × (1 mmol of **2d**/4 mmol of N) = 0.34 mmol **2d**/1 g of compound PC-modified **2d-silica**.

2.5.1 Typical procedure for the surface modification of silica beads using sulfur-bridged alkoxysilanated PC (2e-2h)

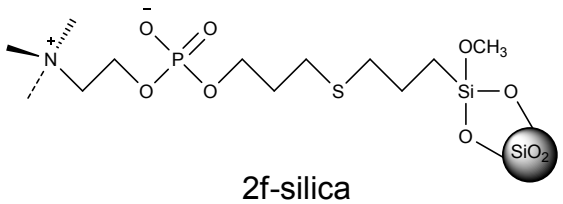
A mixture consisting of sulfur-bridged silanated PC (1 mmol) of (**2e-2h**), 400 mg of amorphous silica balls (Aldrich, USA, 10 μm, 300 m^2g^{-1}) and 20 mL of IPA/toluene (V/V = 1:1) was placed in a 50 mL high pressure vessel and heated at 90 ^oC for 24 h. After cooling to room temperature, the resulted silica was filtered and washed with methanol and toluene, and dried under vacuum to yield a light yellow powder **(2e-2h)-silica.**



2e-silica

2e-silica was obtained as light yellow powder. Found: C, 7.8973; N, 0.7748%. The loading rate for alkoxysilanated PC was based on the N value of modified silica

determined by elemental analysis. For example: calculation of the loading rate of **2e** modified silica **2e-silica** = (0.7748 × 10^{-2} g of N/1 g of compound PC-modified silica **2e-silica**) × (10^3 mmol of N/14 g of N) × (1 mmol of **2e**/1 mmol of N) = 0.55 mmol **2e**/1 g of compound PC-modified **2e-silica**.

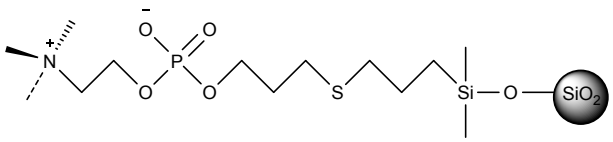


2f-silica

2f-silica was obtained as light yellow powder. Found: C, 9.0929; N, 0.8921%. The loading rate for alkoxysilanated PC was based on the N value of modified silica determined by elemental analysis. For example: calculation of the loading rate of **2f** modified silica **2f-silica** = (0.8921 × 10^{-2} g of N/1 g of compound PC-modified silica **2f-silica**) × (10^3 mmol of N/14 g of N) × (1 mmol of **2f**/1 mmol of N) = 0.63 mmol **2f**/1 g of compound PC-modified **2f-silica**.

2g-silica

2g-silica was obtained as light yellow powder. Found: C, 6.0606; N, 0.5946%. The loading rate for alkoxysilanated PC was based on the N value of modified silica determined by elemental analysis. For example: calculation of the loading rate of **2g** modified silica **2g-silica** = (0.5946 × 10^{-2} g of N/1 g of compound PC-modified silica **2g-silica**) × (10^3 mmol of N/14 g of N) × (1 mmol of **2g**/1 mmol of N) = 0.42 mmol **2g**/1 g of compound PC-modified **2g-silica**.

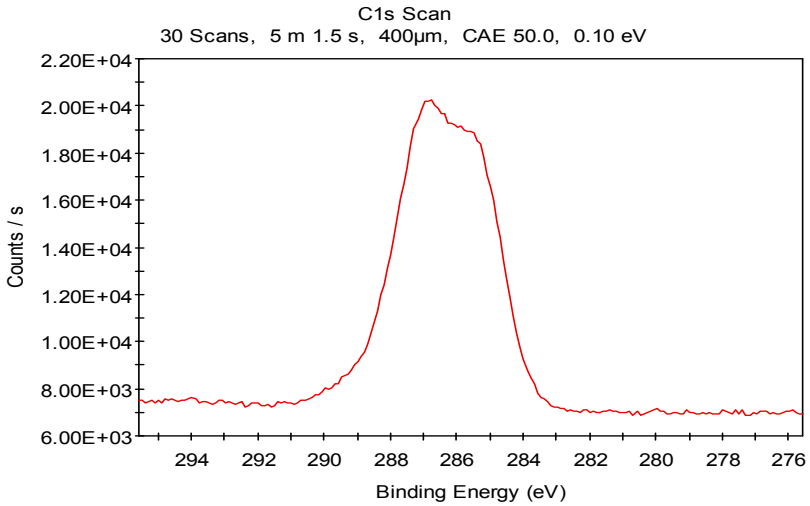


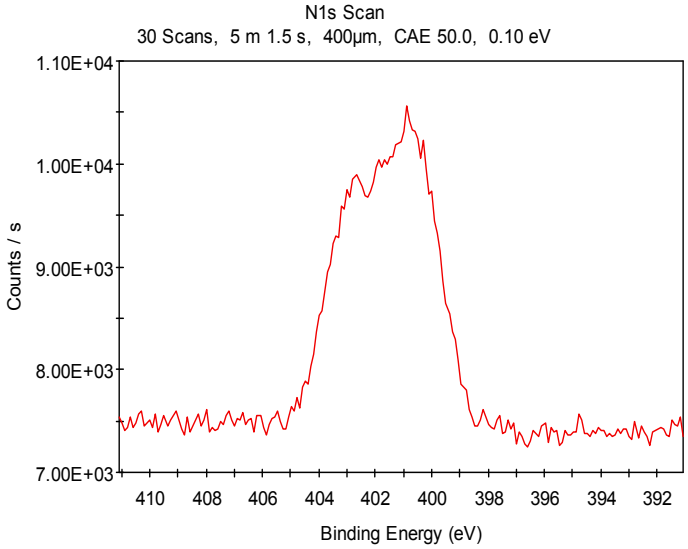
2h-silica

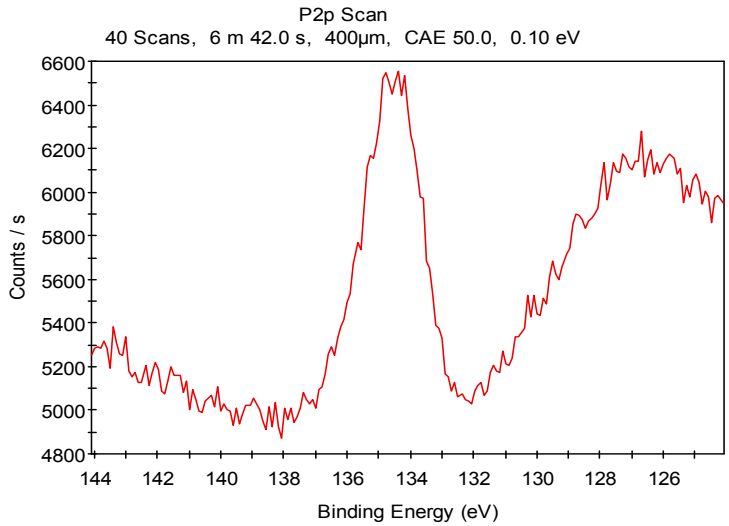
2h-silica was obtained as light yellow powder. Found: C, 6.2050; N, 0.6089%. The loading rate for alkoxysilanated PC was based on the N value of modified silica determined by elemental analysis. For example: calculation of the loading rate of **2h** modified silica **2h-silica** = (0.6089 × 10^{-2} g of N/1 g of compound PC-modified silica **2h-silica**) × (10^{3} mmol of N/14 g of N) × (1 mmol of **2h**/1 mmol of N) = 0.43 mmol **2h**/1 g of compound PC-modified **2h-silica**.

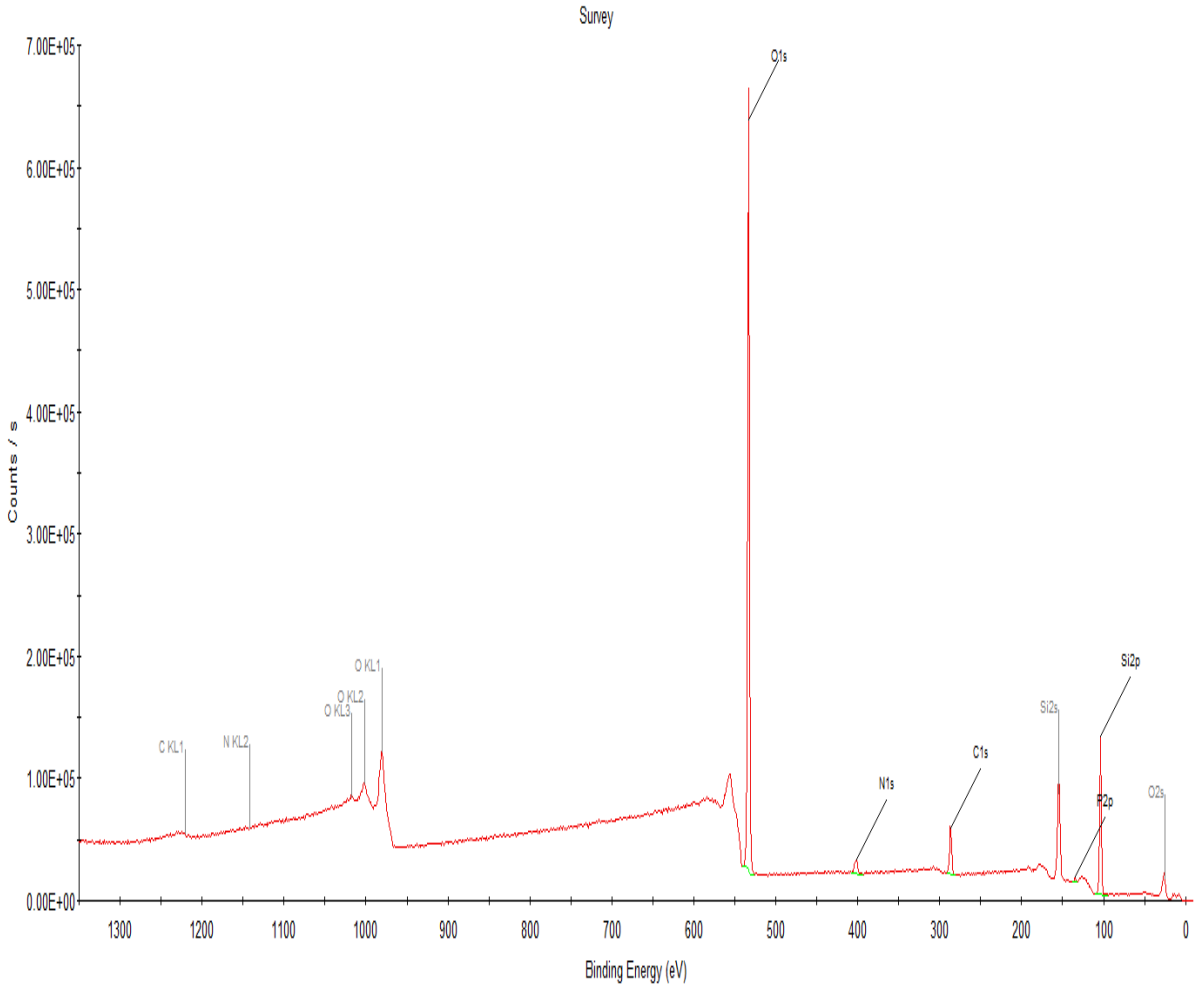
3. XPS spectra of 2c-silica and 2g-silica

3.1 XPS spectra of 2c-silica

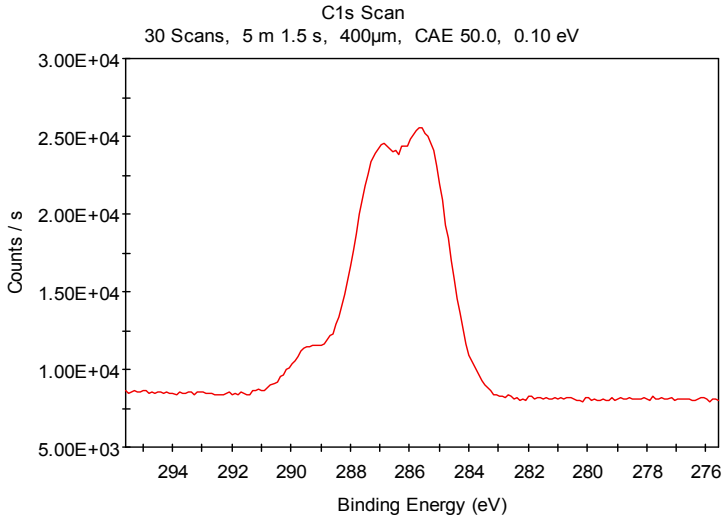


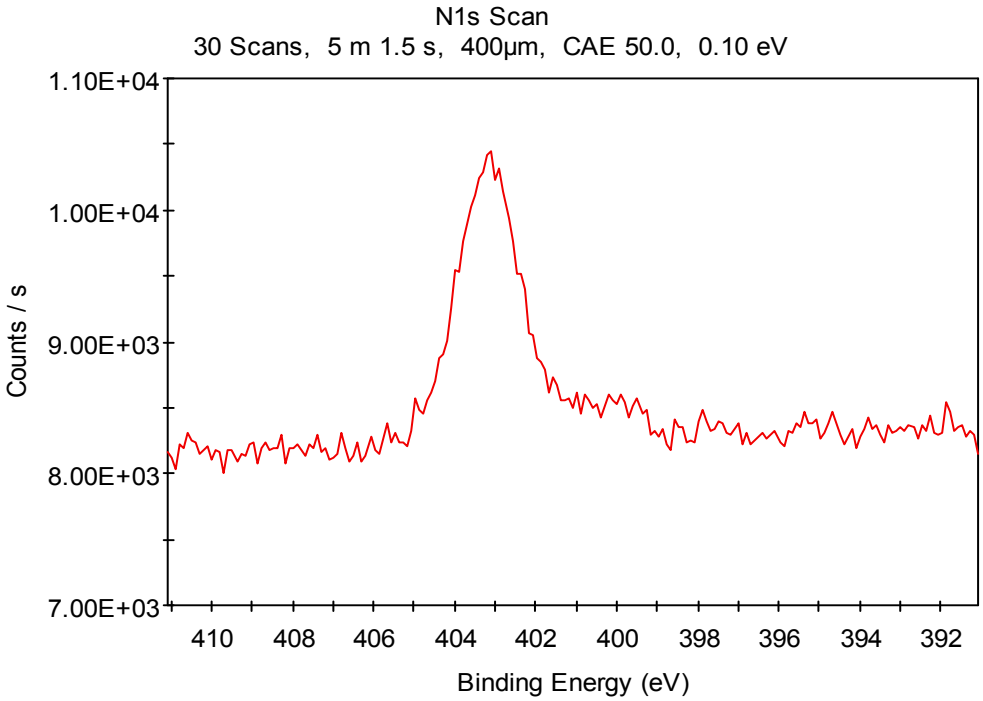

N1s Scan
30 Scans, 5 m 1.5 s, 400µm, CAE 50.0, 0.10 eV
1.10E+04
1.00E+04
9.00E+03
8.00E+03
7.00E+03
Counts / s
410
408
406
404
402
400
398
396
394
392
Binding Energy (eV)

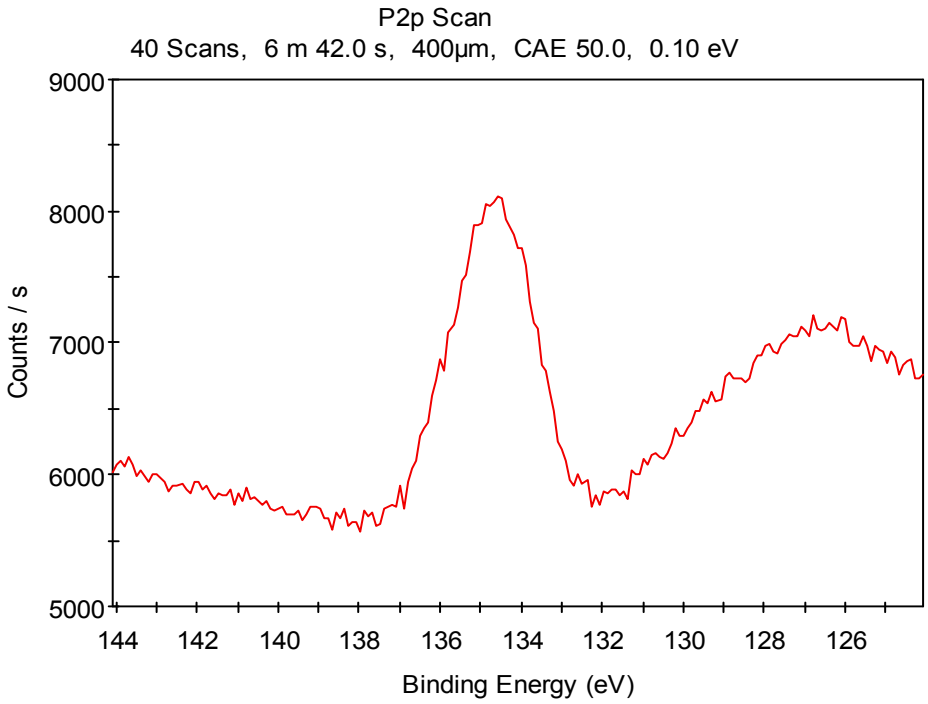

P2p Scan
40 Scans, 6 m 42.0 s, 400µm, CAE 50.0, 0.10 eV
6600
6400
6200
6000
5800
5600
5400
5200
5000
4800
Counts / s
144
142
140
138
136
134
132
130
128
126
Binding Energy (eV)

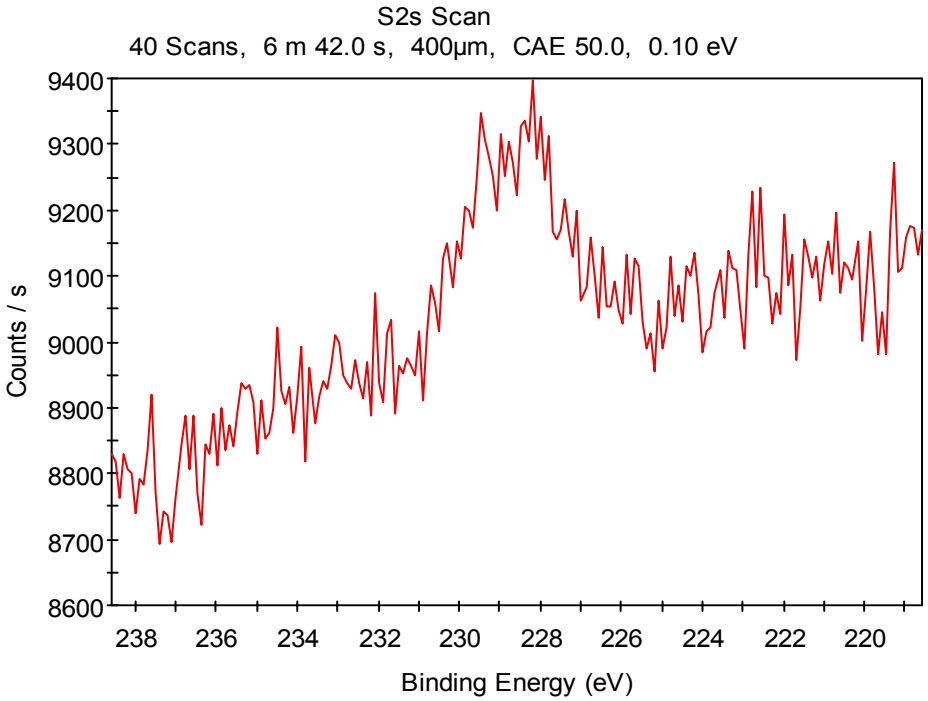


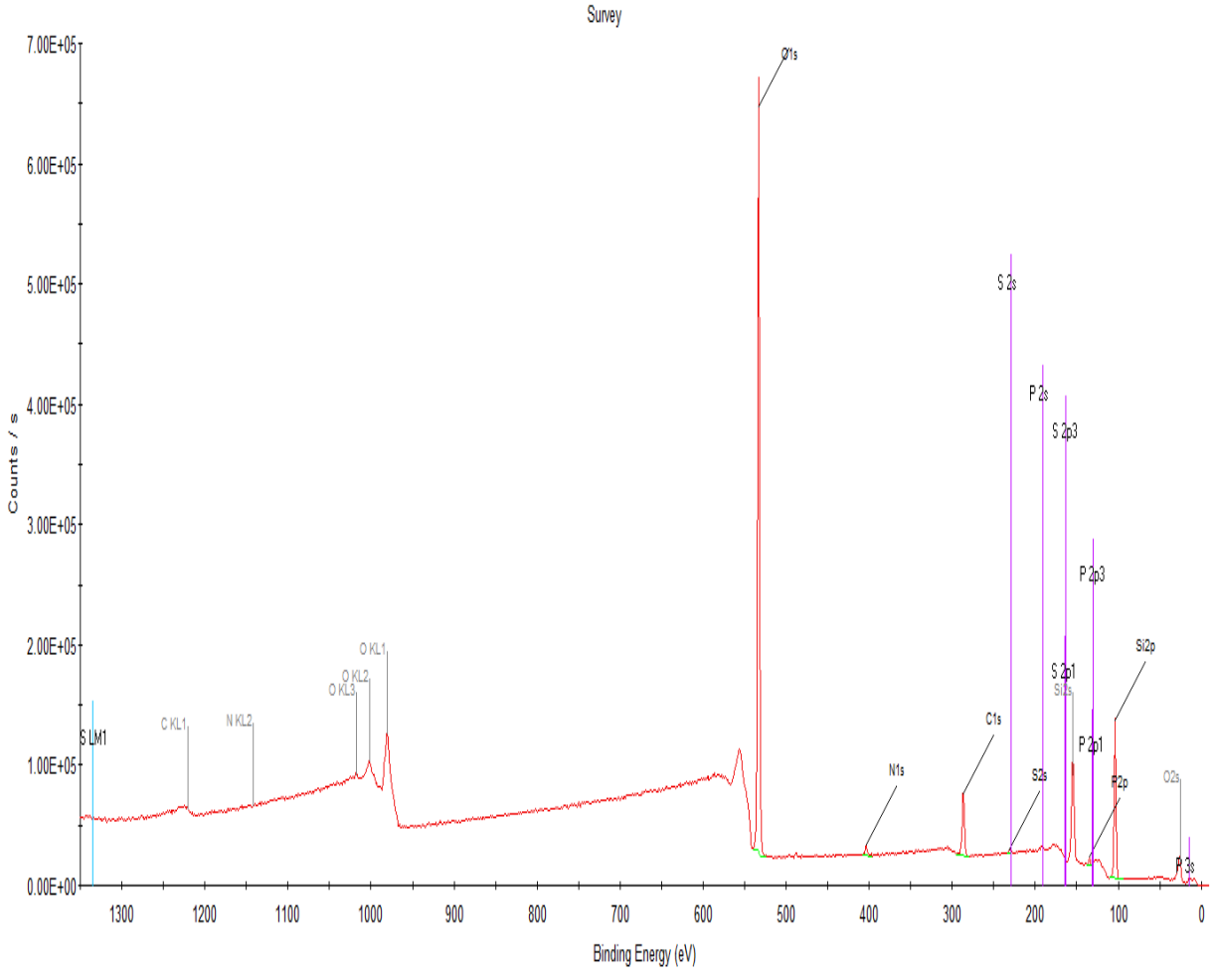
3.2 XPS spectra of 2g-silica




N1s Scan
30 Scans, 5 m 1.5 s, 400µm, CAE 50.0, 0.10 eV
1.10E+04
1.00E+04
9.00E+03
8.00E+03
7.00E+03
Counts / s
410
408
406
404
402
400
398
396
394
392
Binding Energy (eV)


P2p Scan
40 Scans, 6 m 42.0 s, 400µm, CAE 50.0, 0.10 eV
9000
8000
7000
6000
5000
Counts / s
144
142
140
138
136
134
132
130
128
126
Binding Energy (eV)


S2s Scan
40 Scans, 6 m 42.0 s, 400µm, CAE 50.0, 0.10 eV
Counts / s
9400
9300
9200
9100
9000
8900
8800
8700
8600
238
236
234
232
230
228
226
224
222
220
Binding Energy (eV)


Survey
Counts / s
7.00E+05
6.00E+05
5.00E+05
4.00E+05
3.00E+05
2.00E+05
1.00E+05
0.00E+00
O1s
S 2s
P 2s
S 2p3
P 2p3
Si2p
S 2p1
Si2s
P 2p1
C1s
N1s
S2s
P2p
O2s
P 3s
S LM1
C KL1
N KL2
O KL3
O KL2
O KL1
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
Binding Energy (eV)

4.0 NMR spectra of representive products

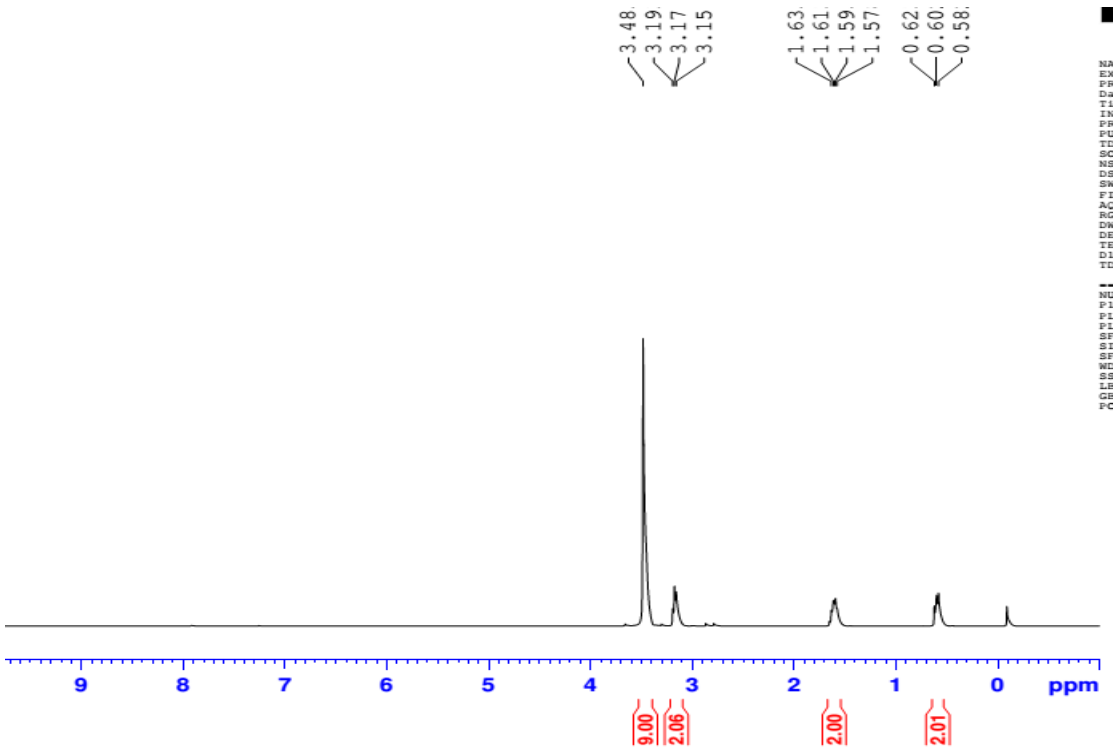


Fig.1 H-NMR of 1a

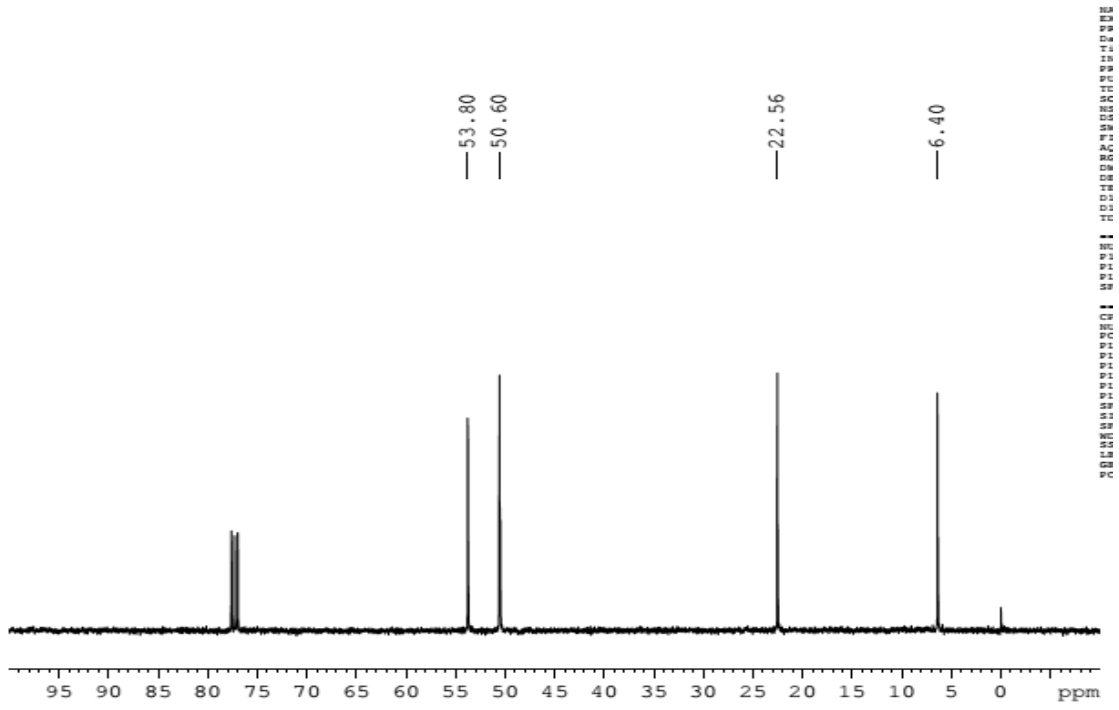


Fig.2 C-NMR of 1a

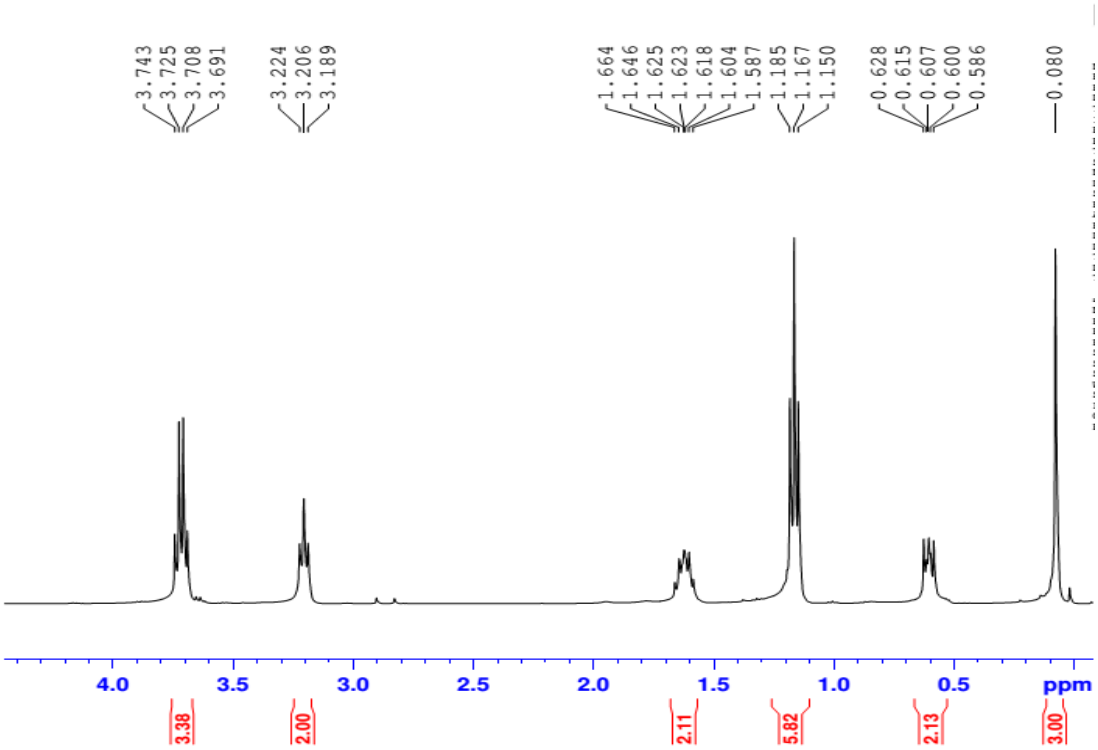


Fig.3 H-NMR of 1b

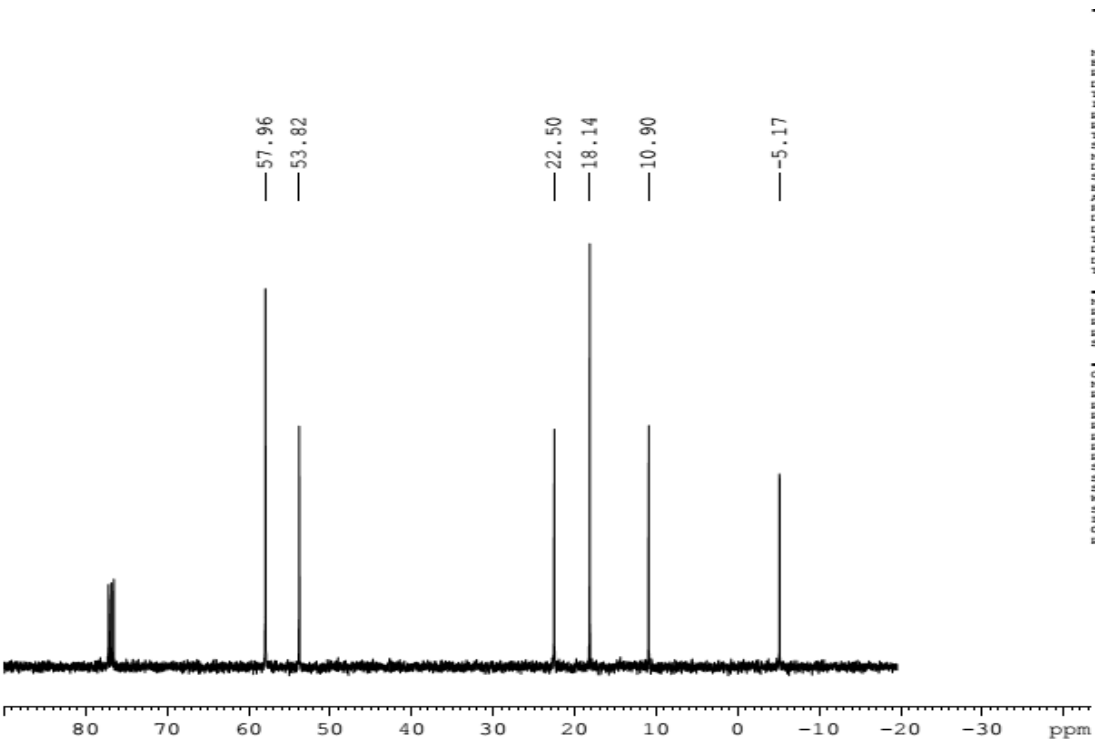


Fig.4 C-NMR of 1b

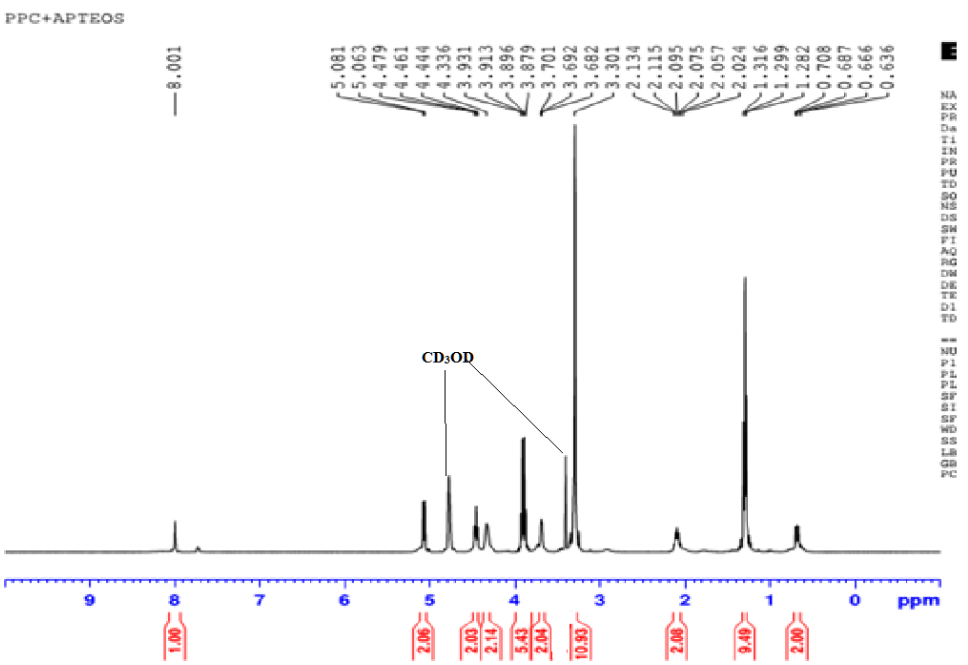


Fig.5 H-NMR of 2b

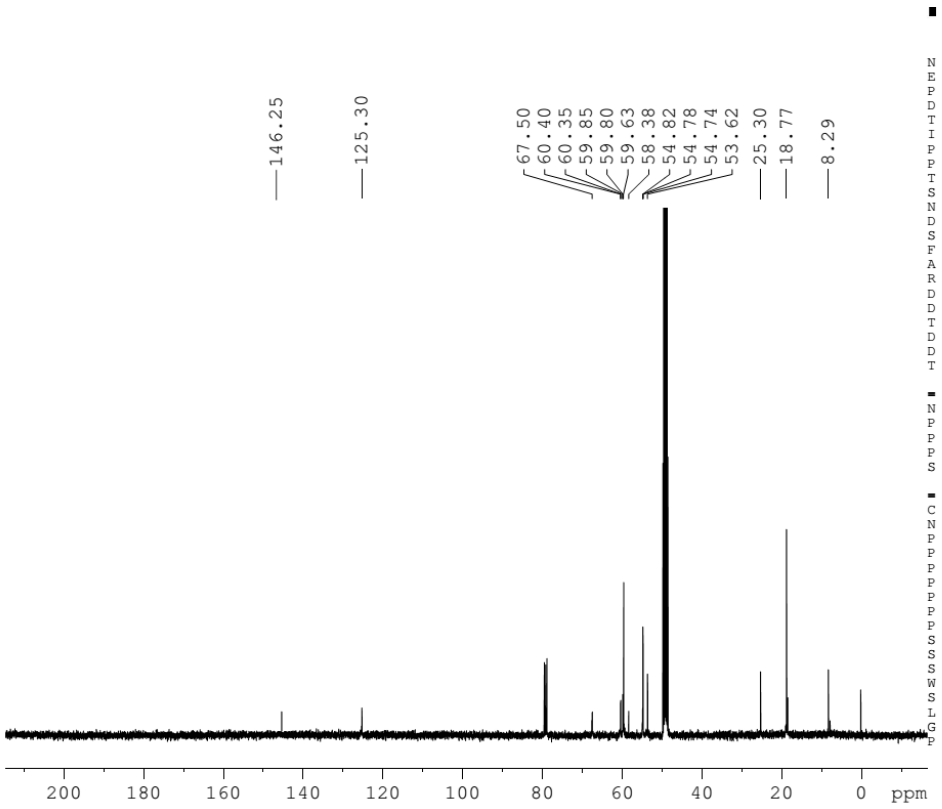


Fig.6 C-NMR of 2b

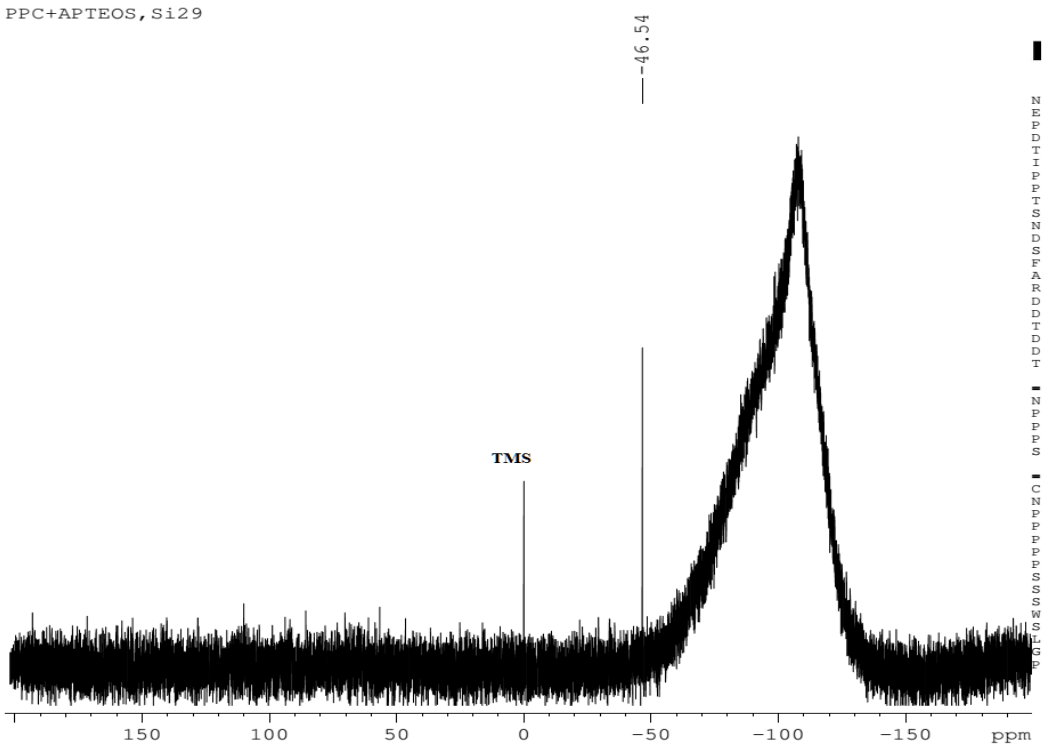


Fig.7 Si-NMR of 2b

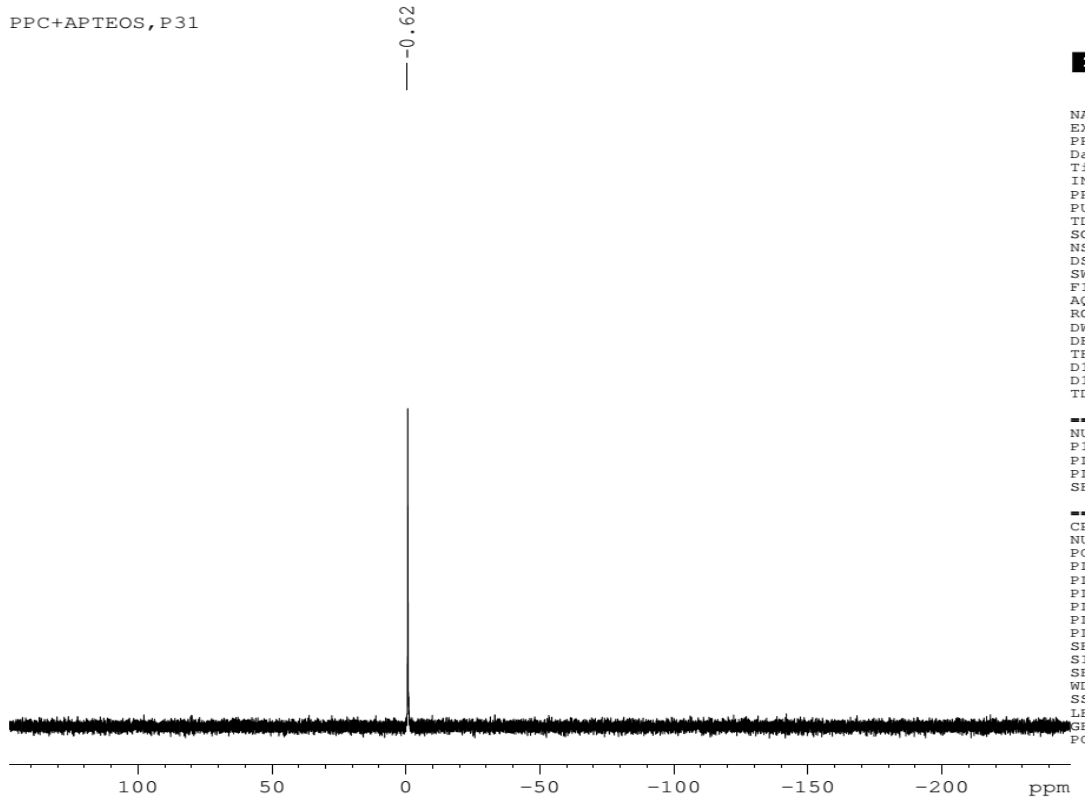


Fig.8 P-NMR OF 2b

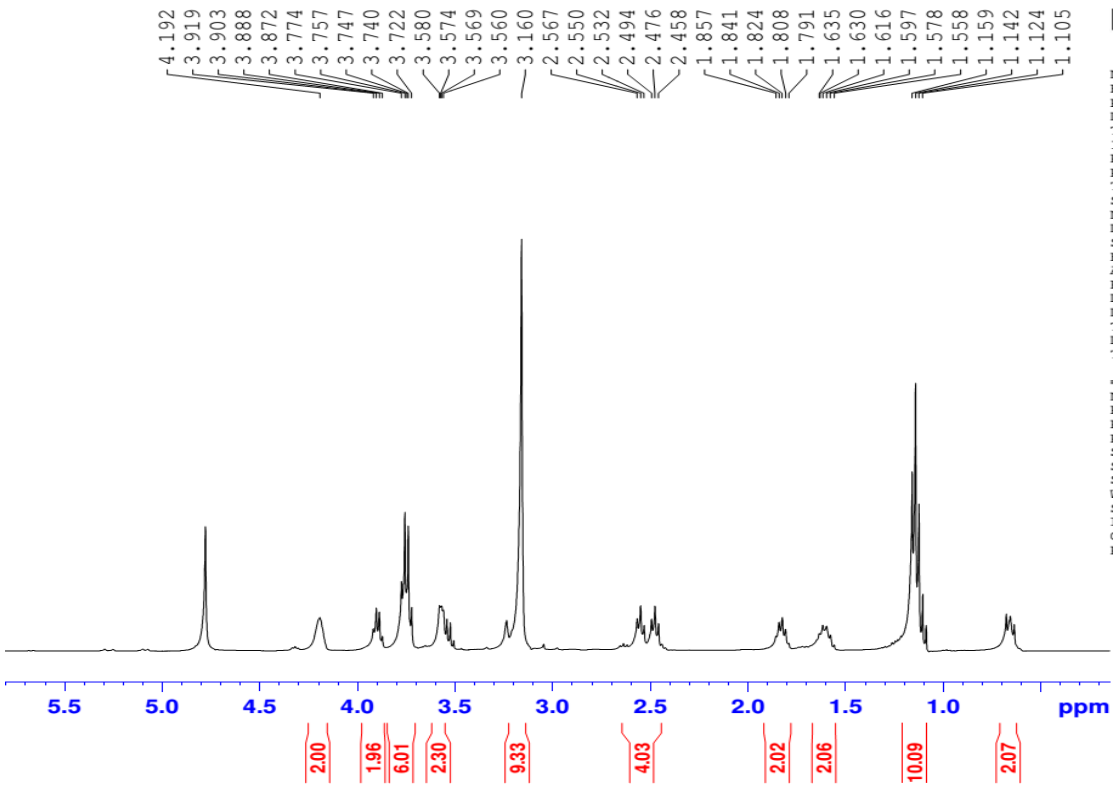


Fig.9 H-NMR of 2e

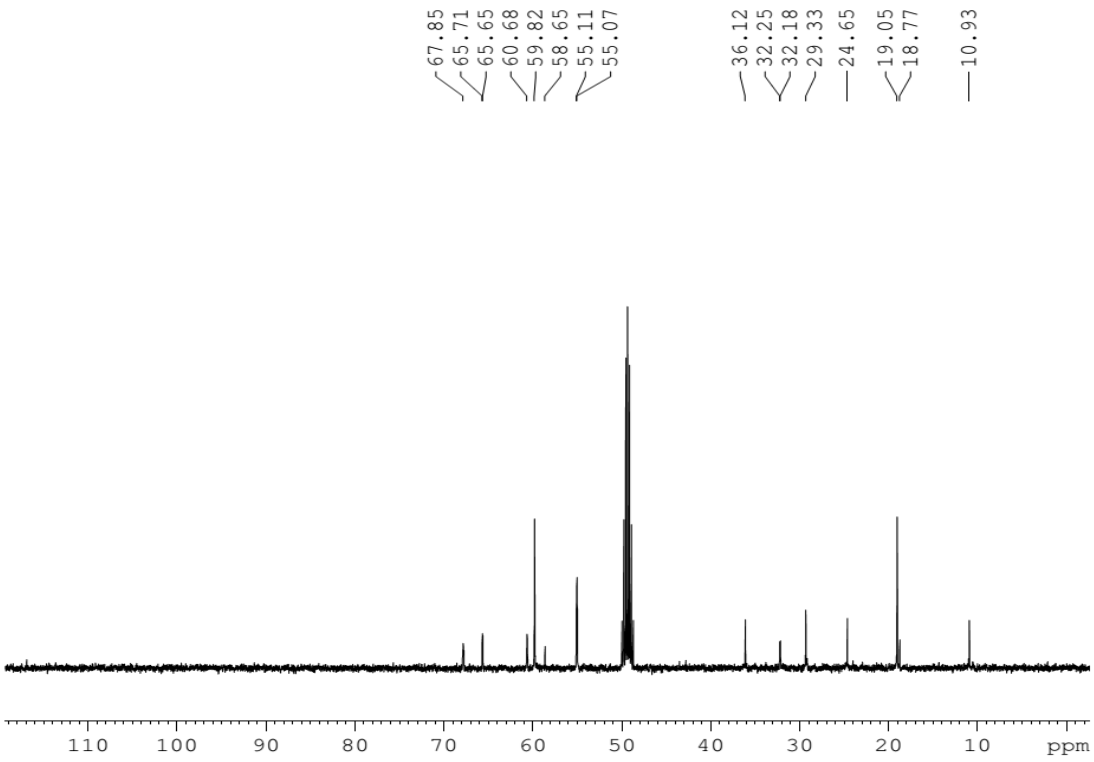


Fig.10 C-NMR of 2e

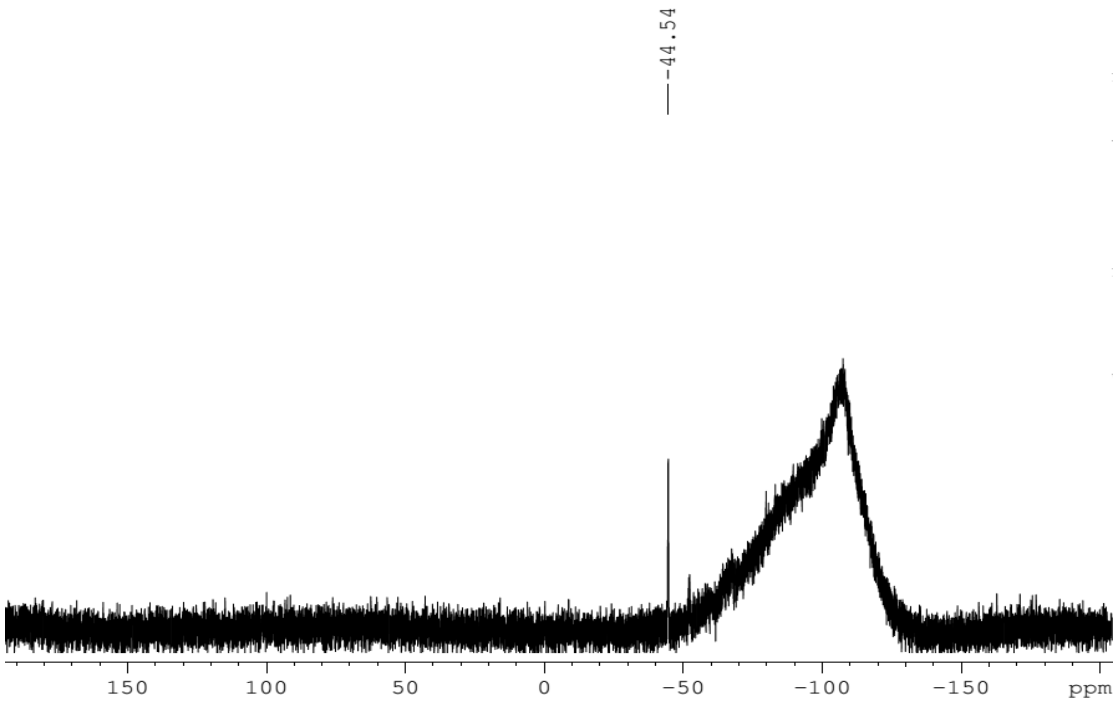


Fig.11 Si-NMR of 2e

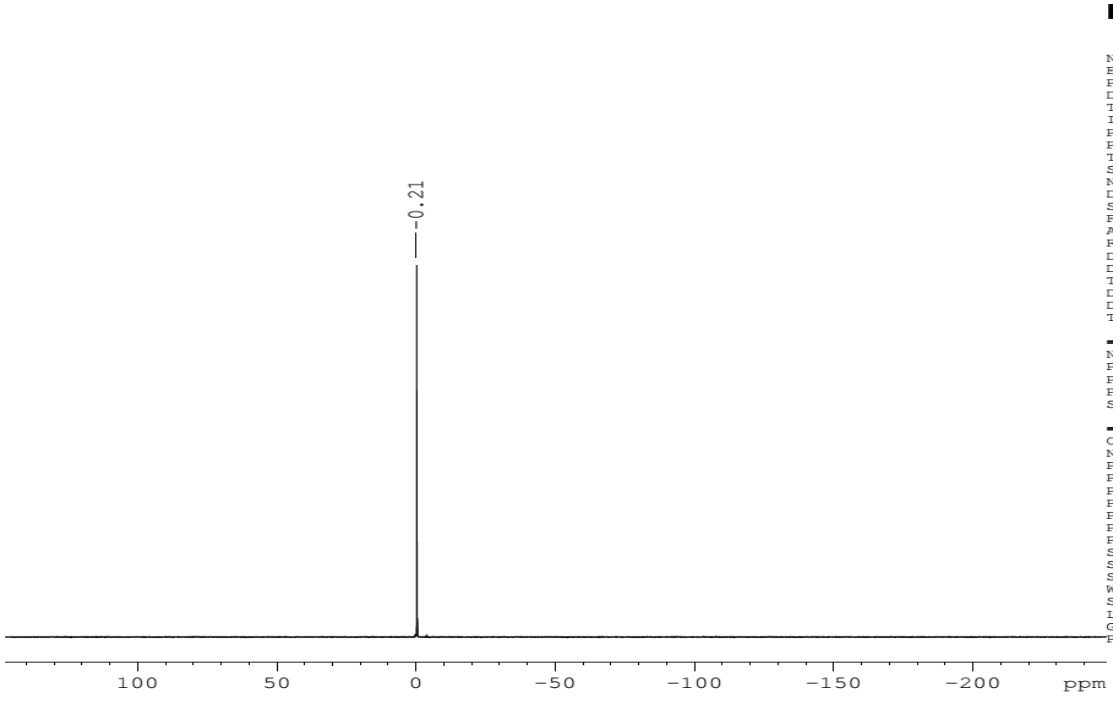


Fig.12 P-NMR of 2e