

Supporting information

## **Polyether-tethered imidazole-2-thiones, imidazole-2-selenones and imidazolium salts as collectors for the flotation of lithium aluminate and spodumene**

Sophie Acker, Jan C. Namyslo, Martin Rudolph, Franziska Strube, Ursula E. A. Fittschen, Hao Qiu, Daniel Goldmann, and Andreas Schmidt\*

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# 1. NMR spectra of 2a

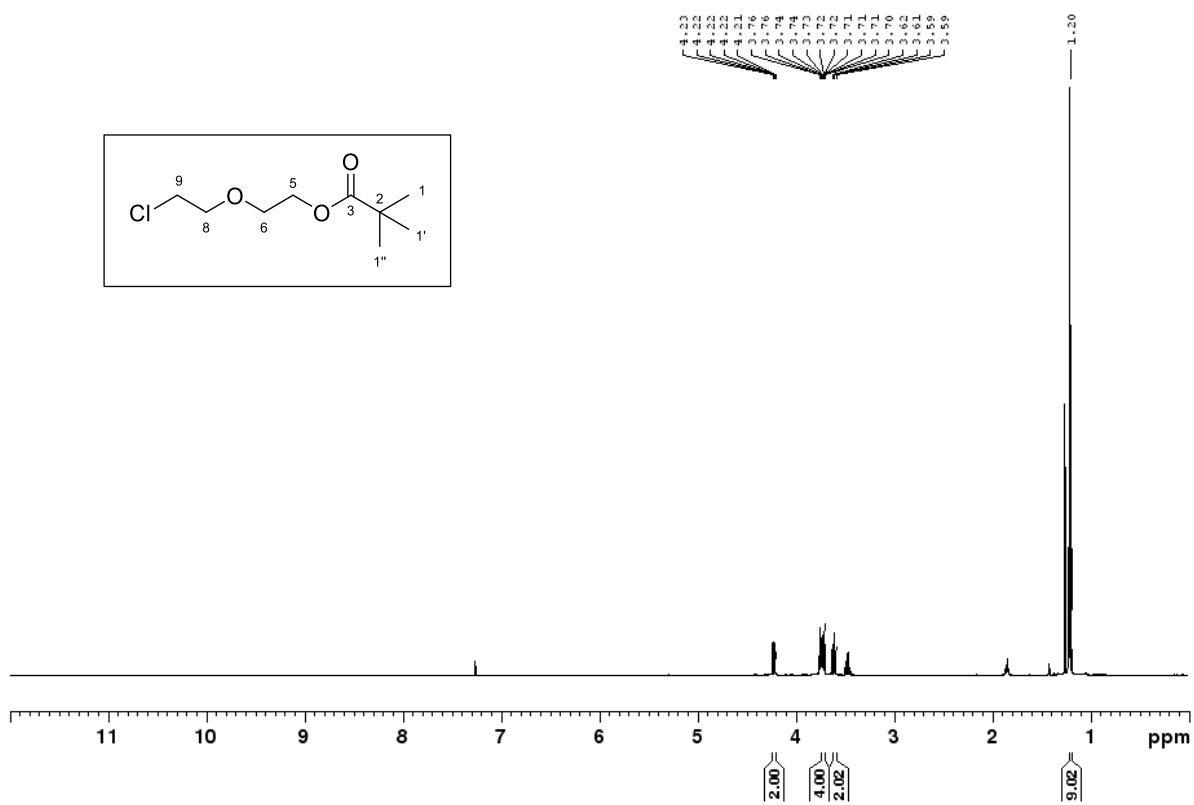


Figure 1: <sup>1</sup>H-NMR of 2a.

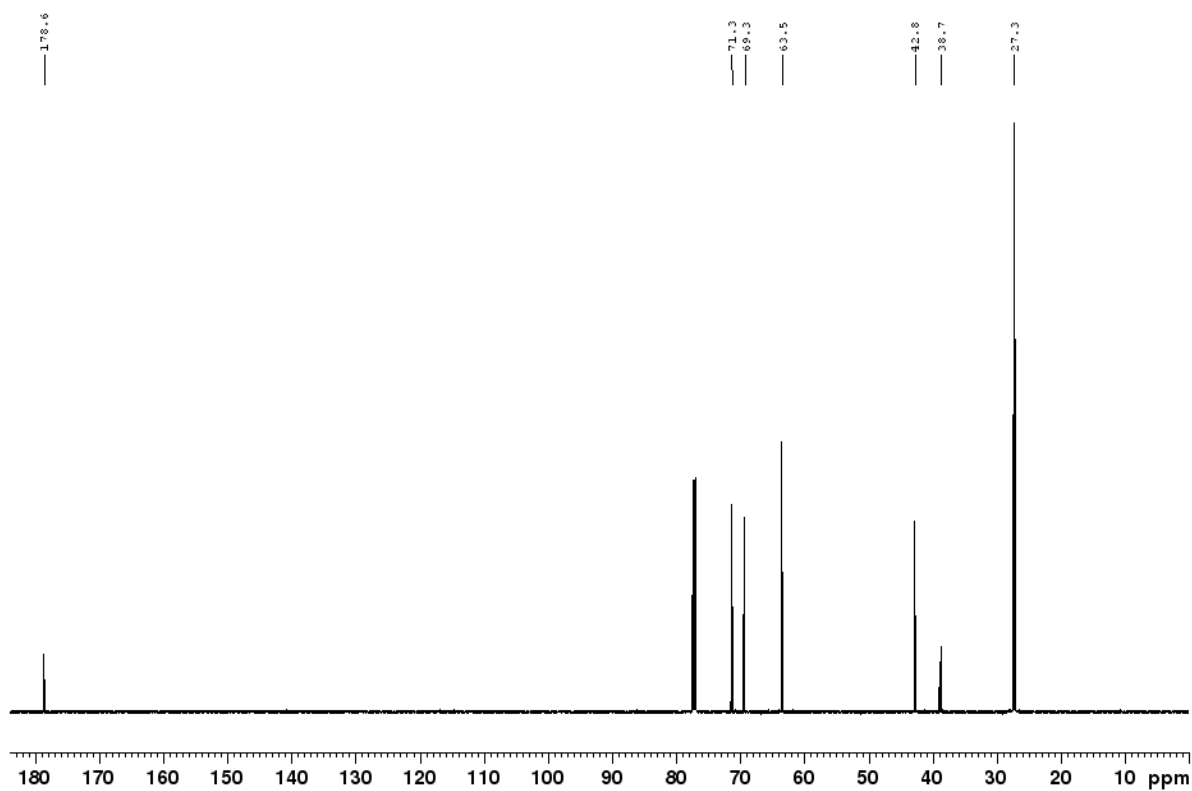


Figure 2: <sup>13</sup>C-NMR of 2a.

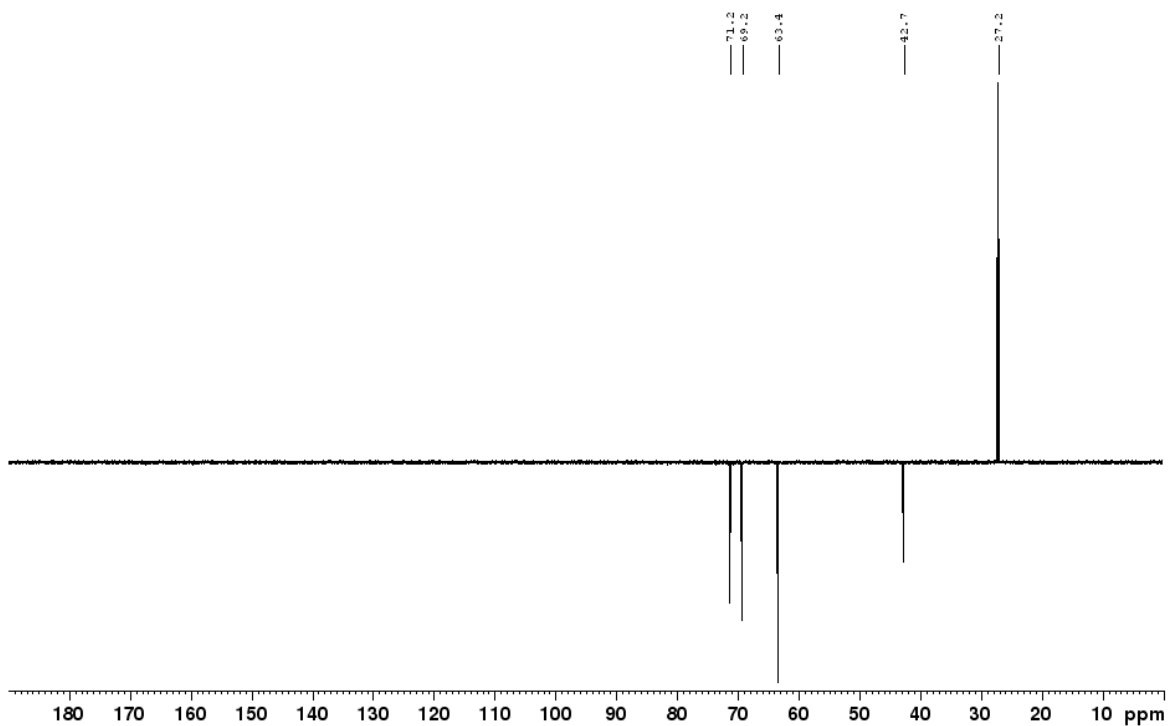


Figure 3: DEPT-135-spectrum of 2a.

## 2. NMR spectra of 2b

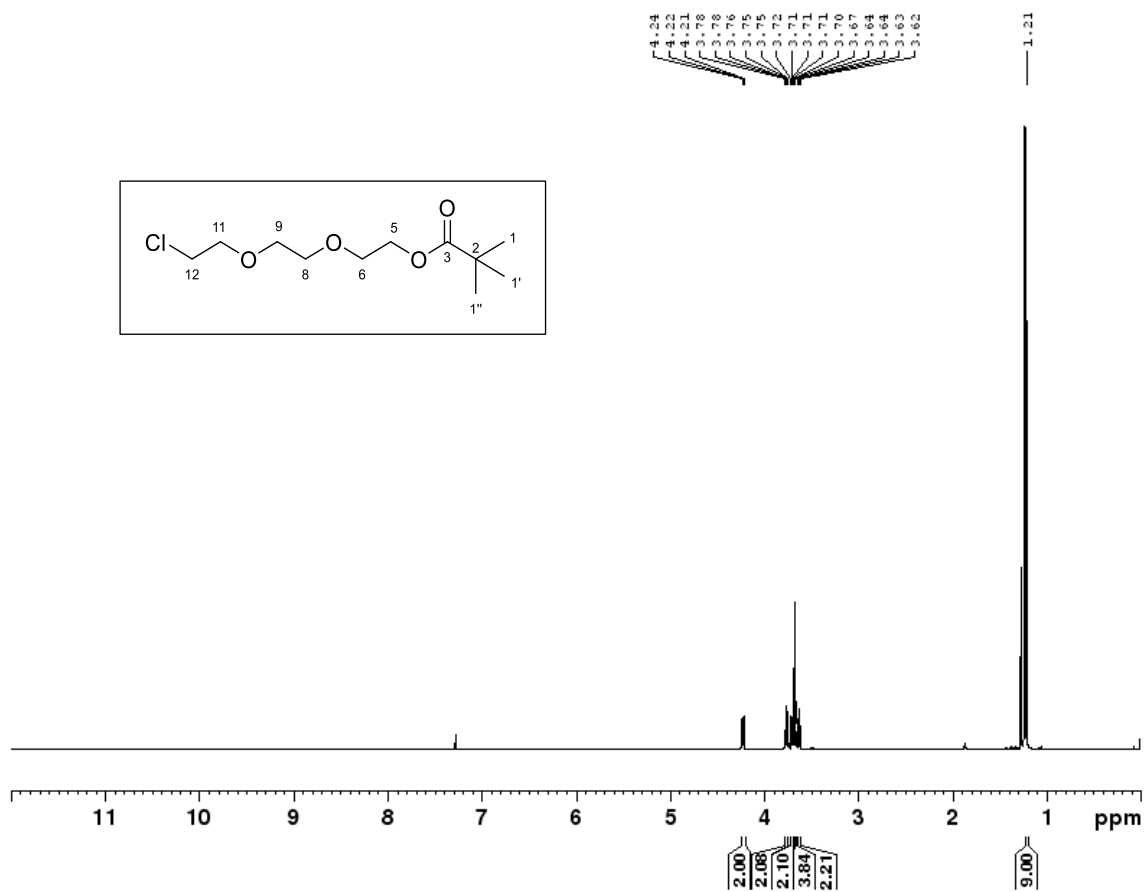


Figure 4:  $^1\text{H}$ -NMR of 2b.

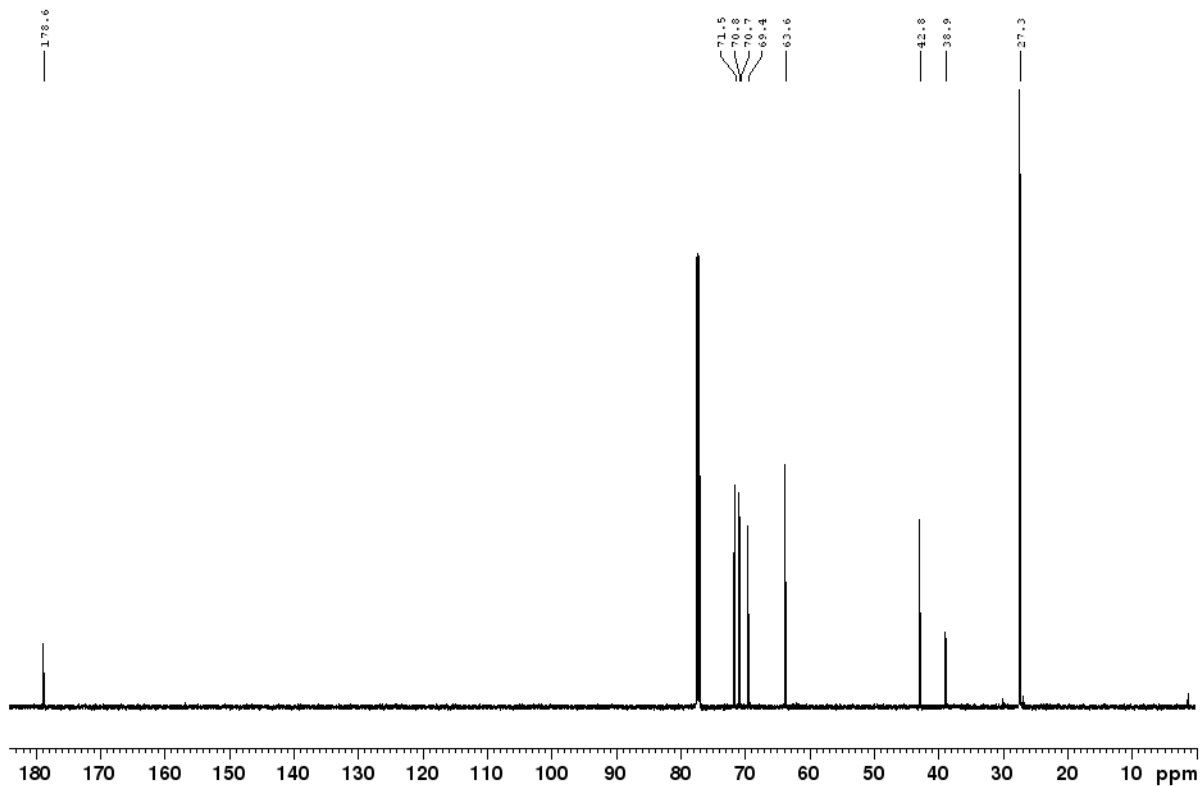


Figure 5:  $^{13}\text{C}$ -NMR of 2b.

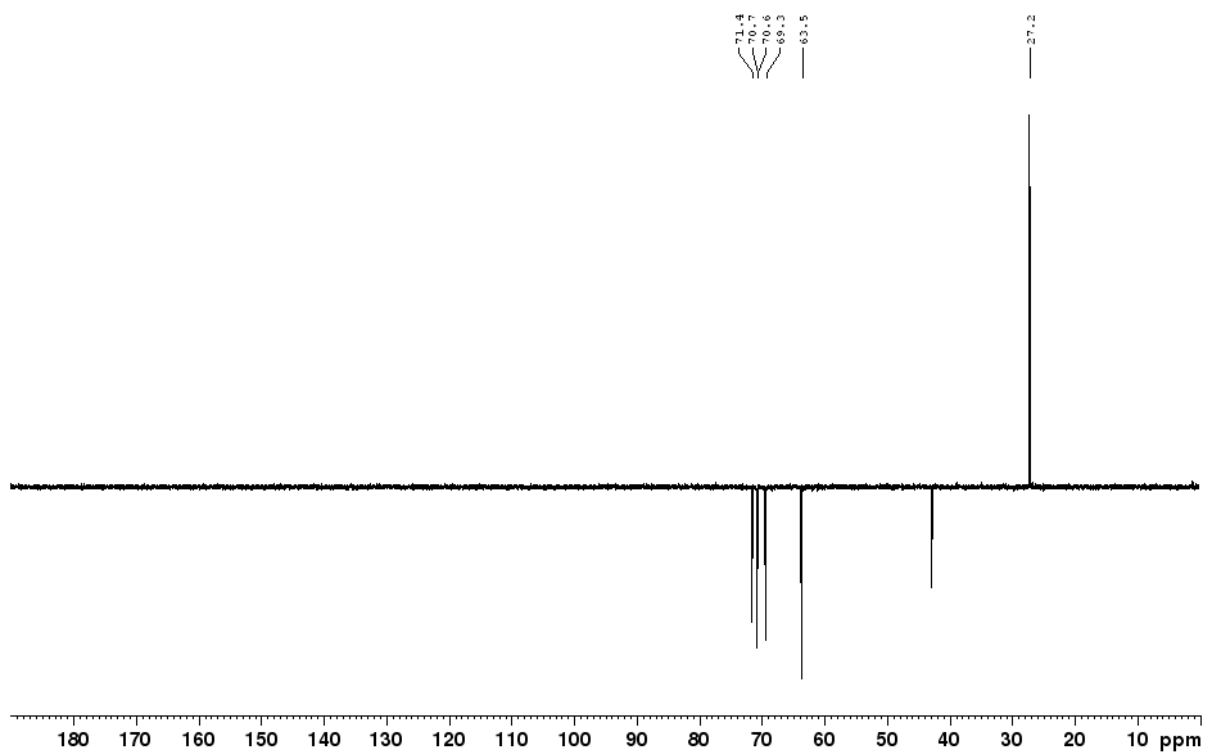


Figure 6: DEPT-135-spectrum of 2b.

### 3. NMR spectra of 3a

The spectra show impurities of the precursor compound **2b** which could not be separated by common purification methods.

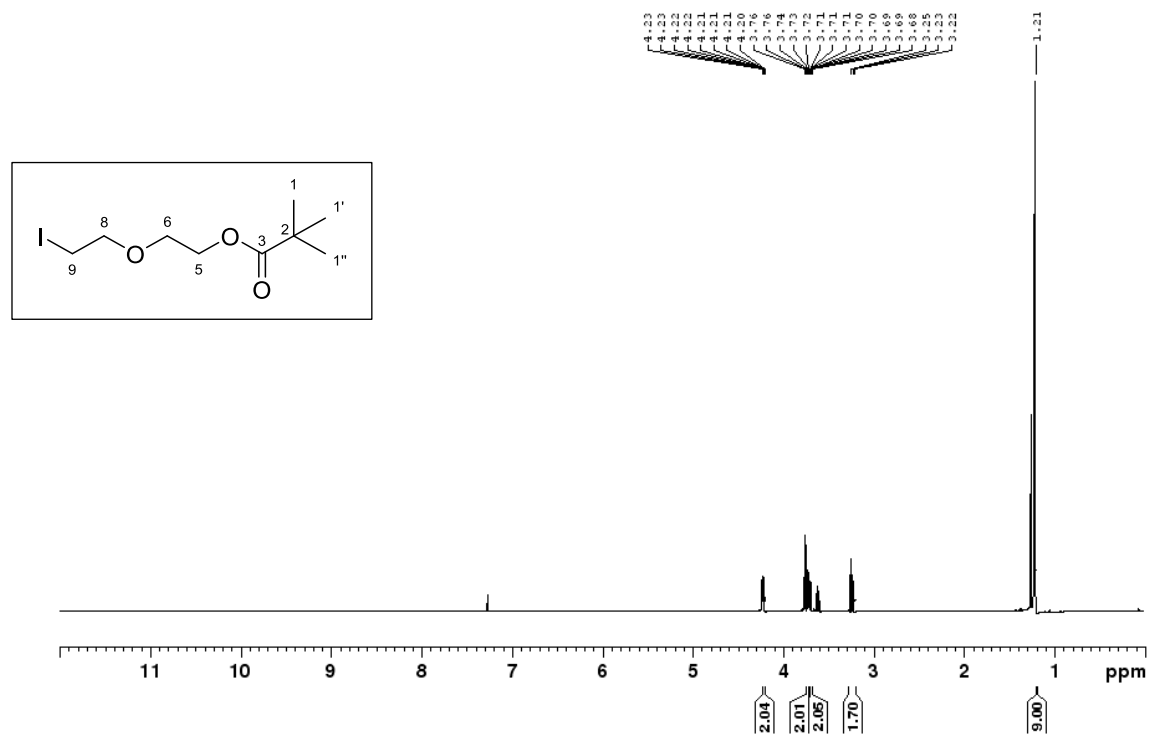


Figure 7: <sup>1</sup>H-NMR of 3a.

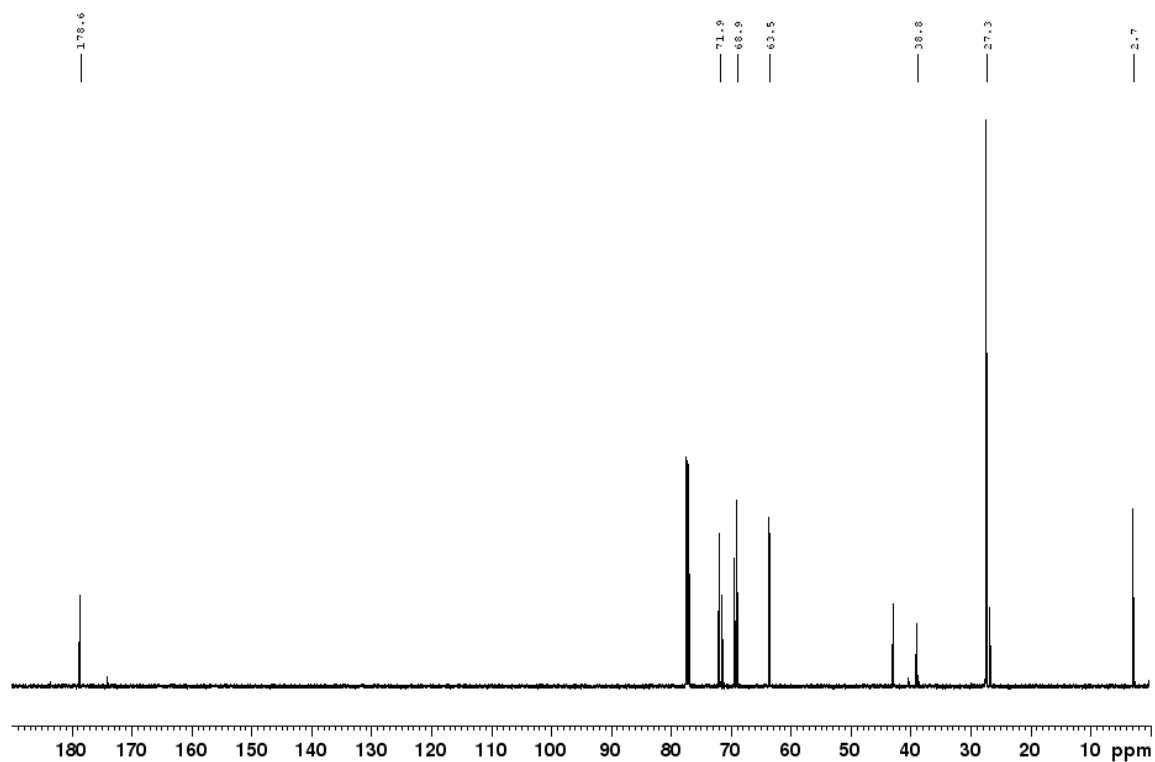


Figure 8: <sup>13</sup>C-NMR of 3a.

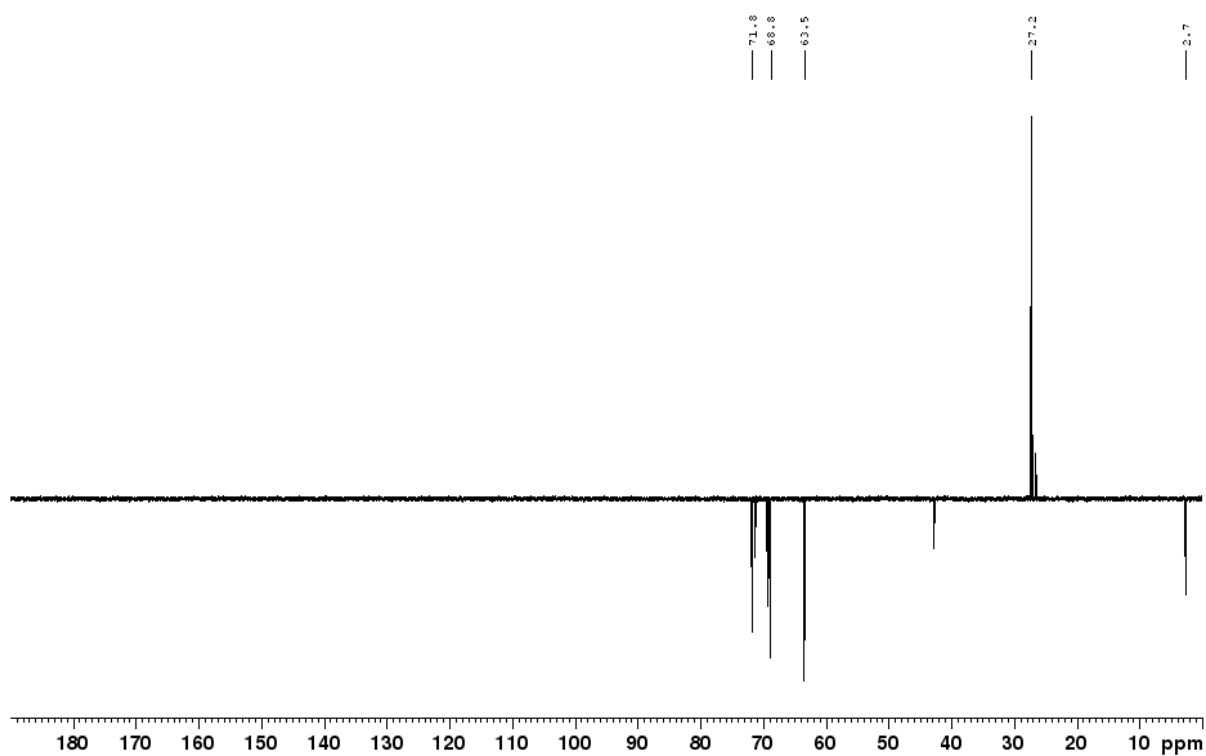


Figure 9: DEPT-135-spectrum of 3a.

#### 4. NMR spectra of 3b

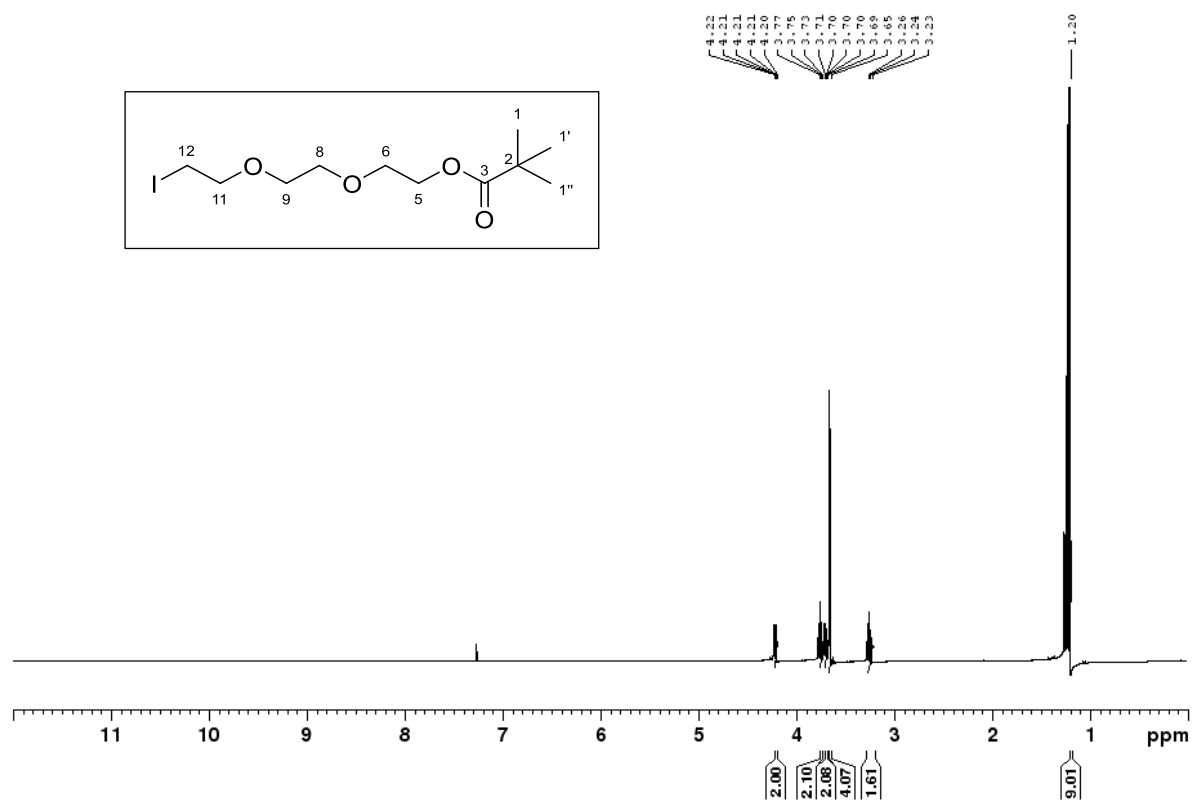


Figure 10:  $^1\text{H}$ -NMR of 3b.

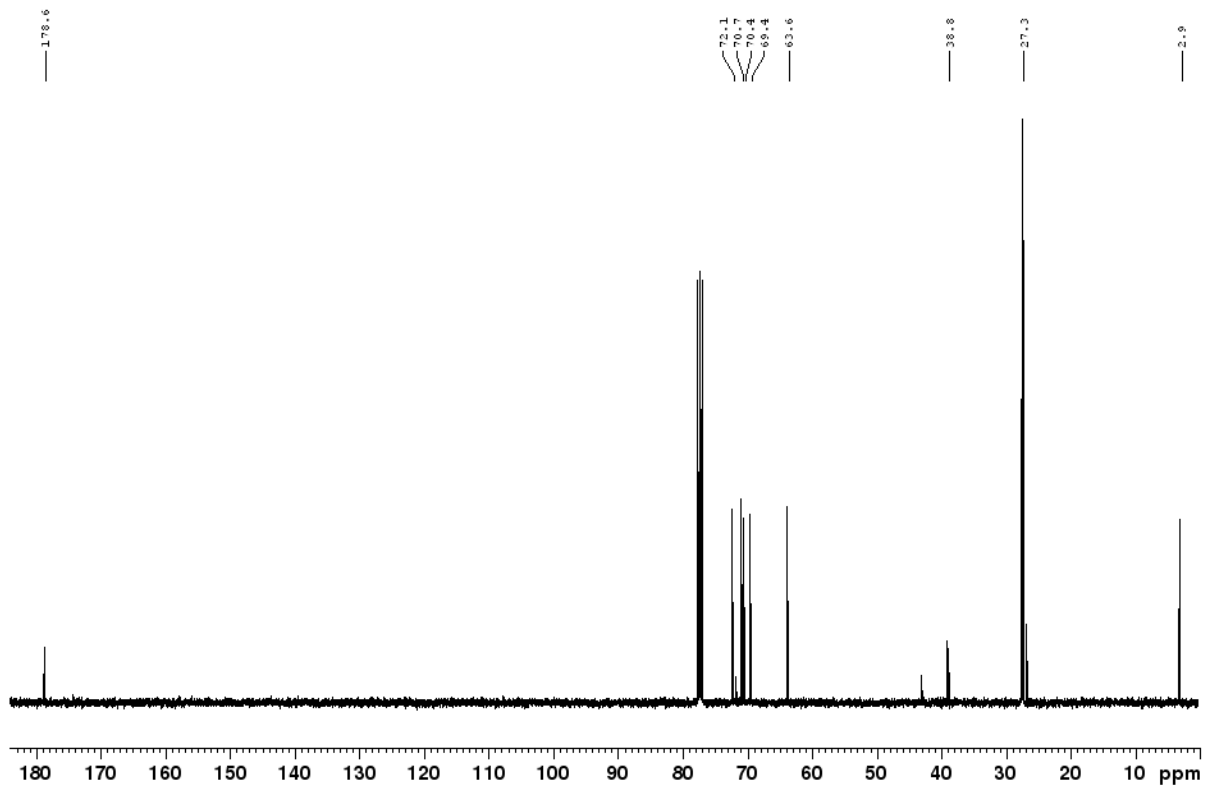


Figure 11:  $^{13}\text{C}$ -NMR of 3b.

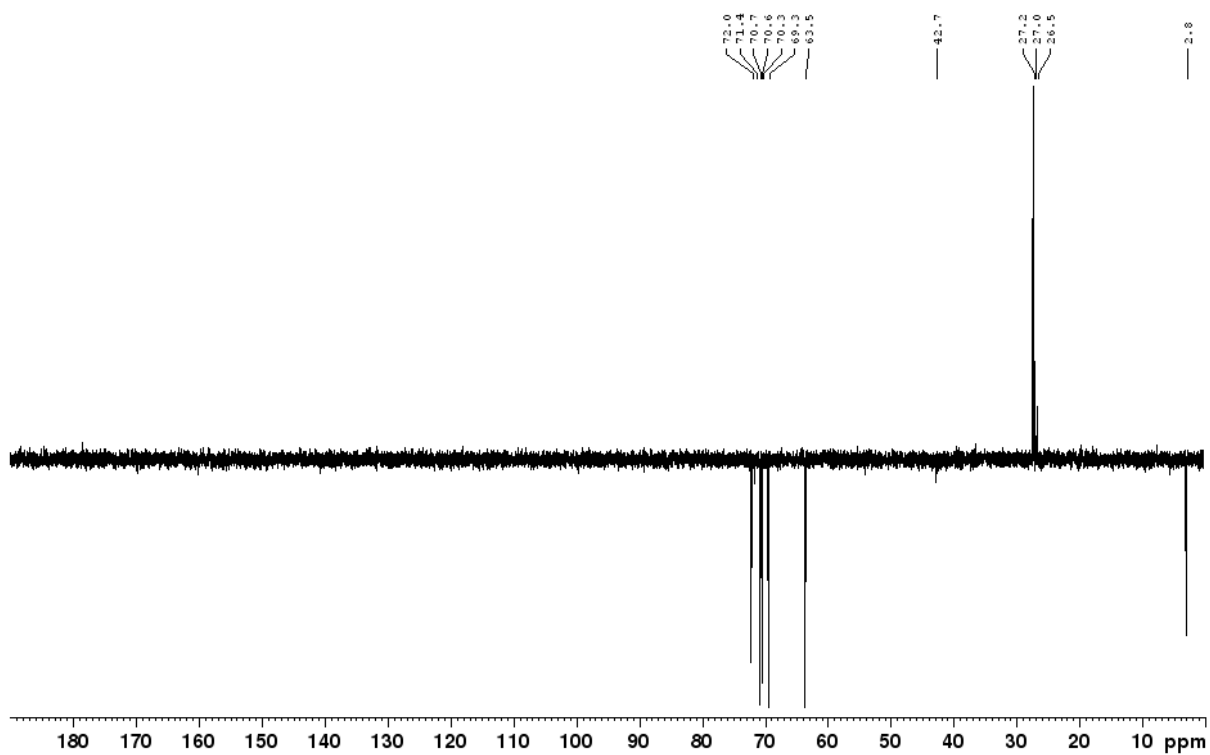


Figure 12: DEPT-135-spectrum of 3b.

## 5. NMR spectra of 4a

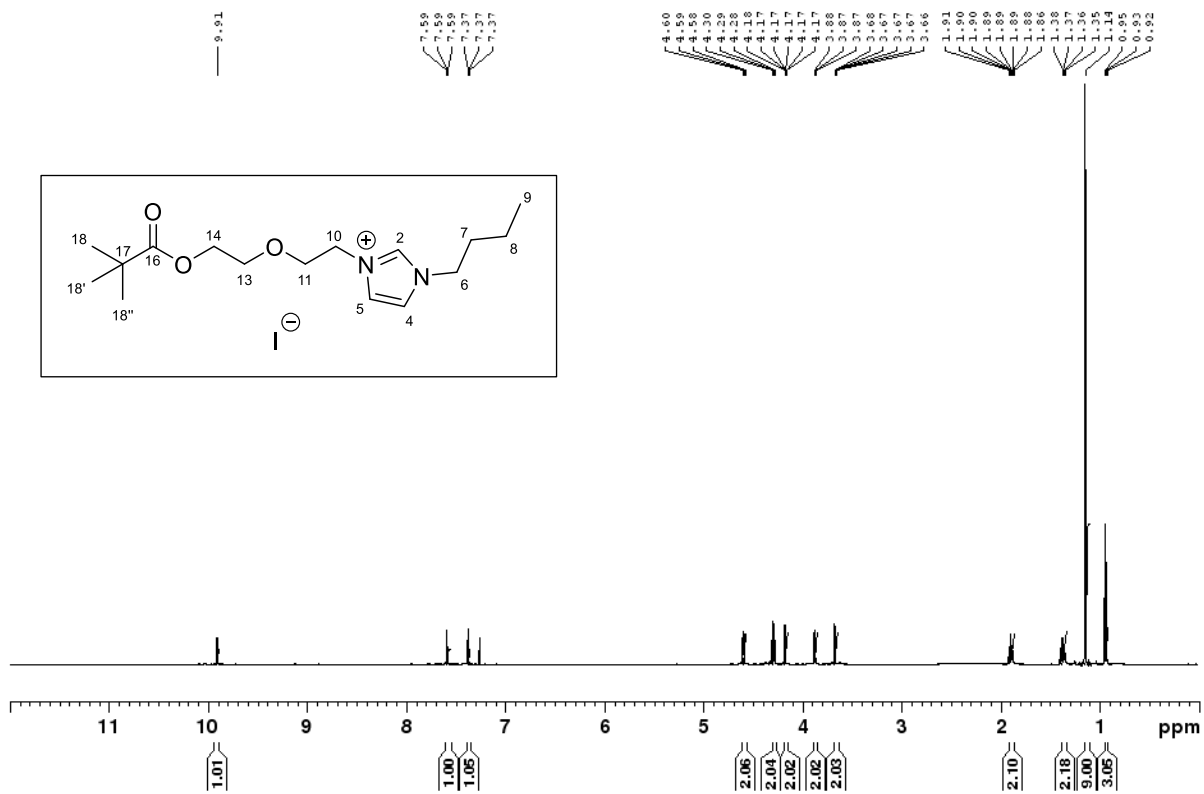


Figure 13: <sup>1</sup>H-NMR of 4a.

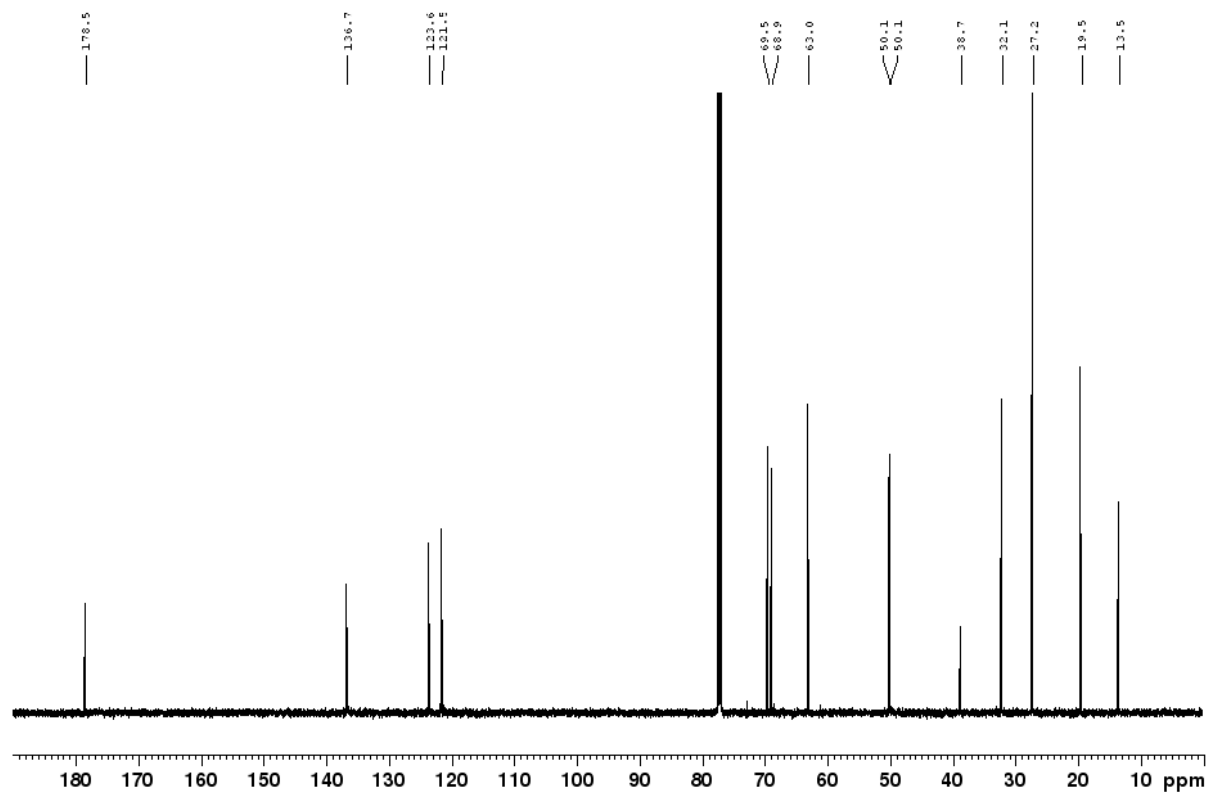


Figure 14: <sup>13</sup>C-NMR of 4a.



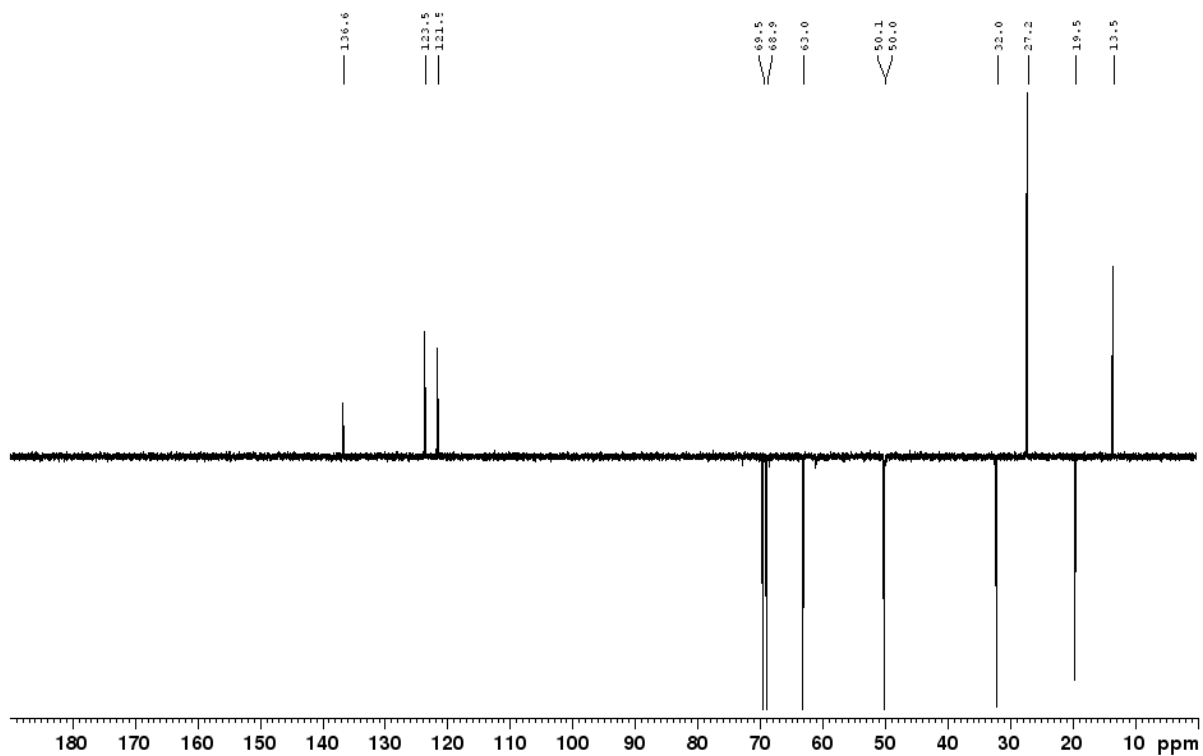


Figure 15: DEPT-135-spectrum of 4a.

## 6. NMR spectra of 4b

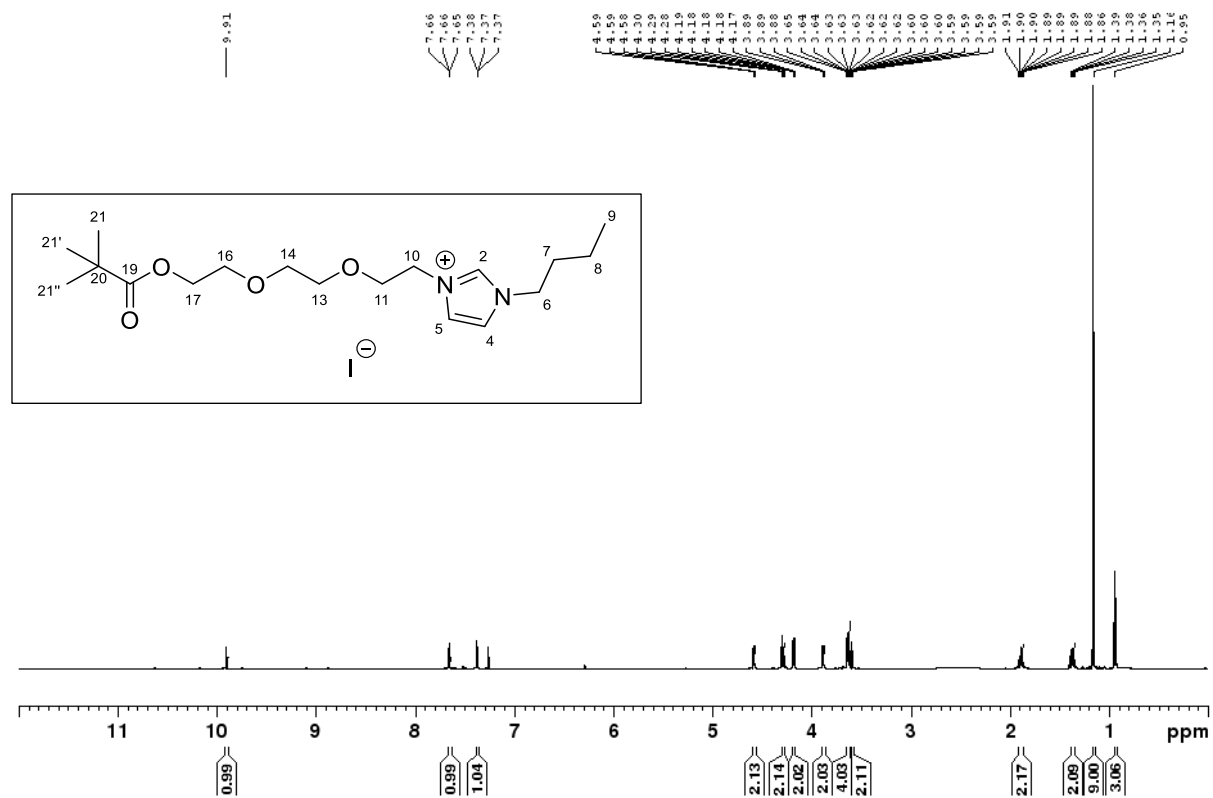


Figure 16:  $^1\text{H}$ -NMR of 4b.

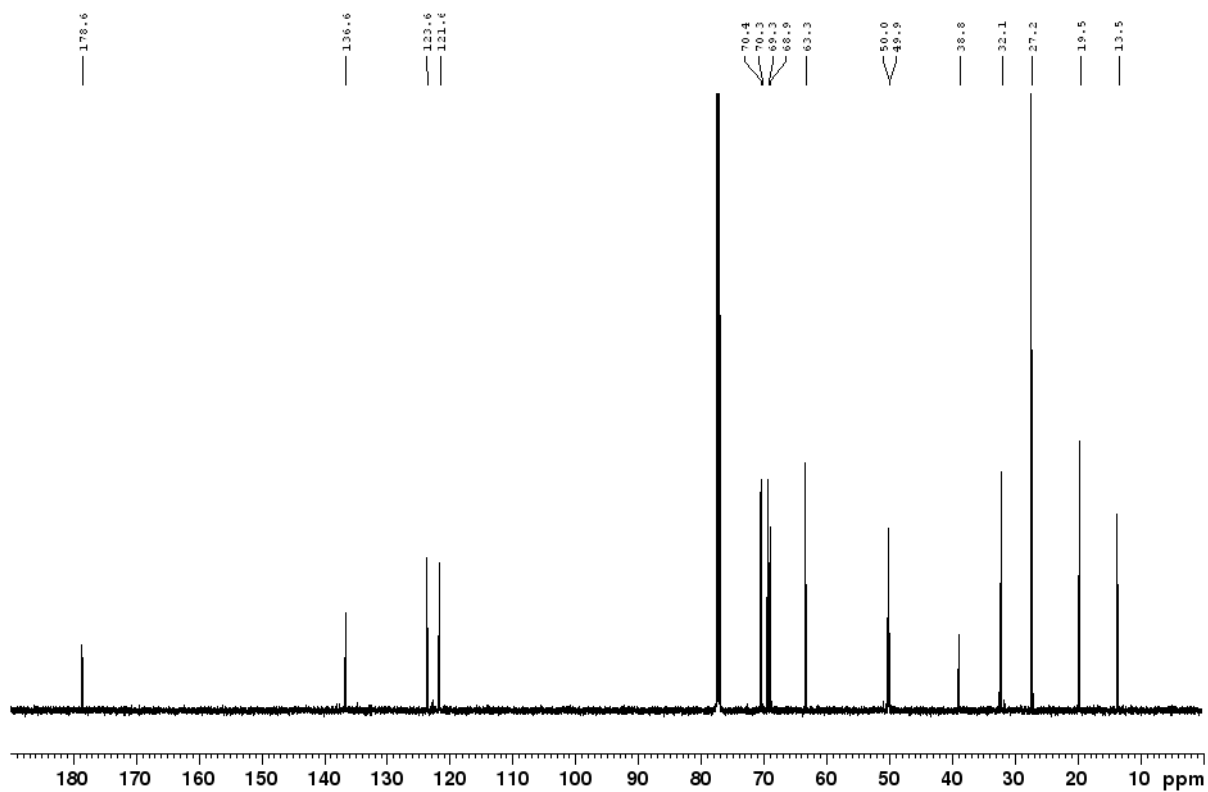


Figure 17:  $^{13}\text{C}$ -NMR of 4b.

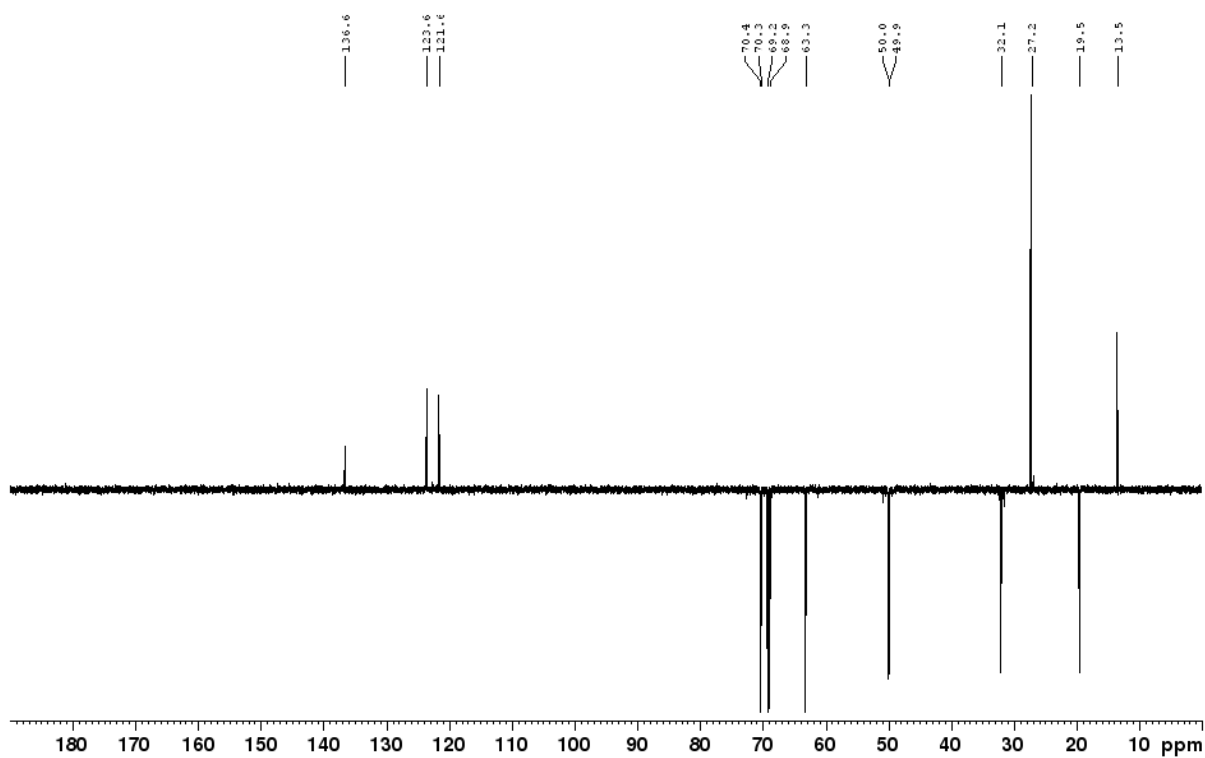


Figure 18: DEPT-135-spectrum of 4b.

## 7. NMR spectra of 5a

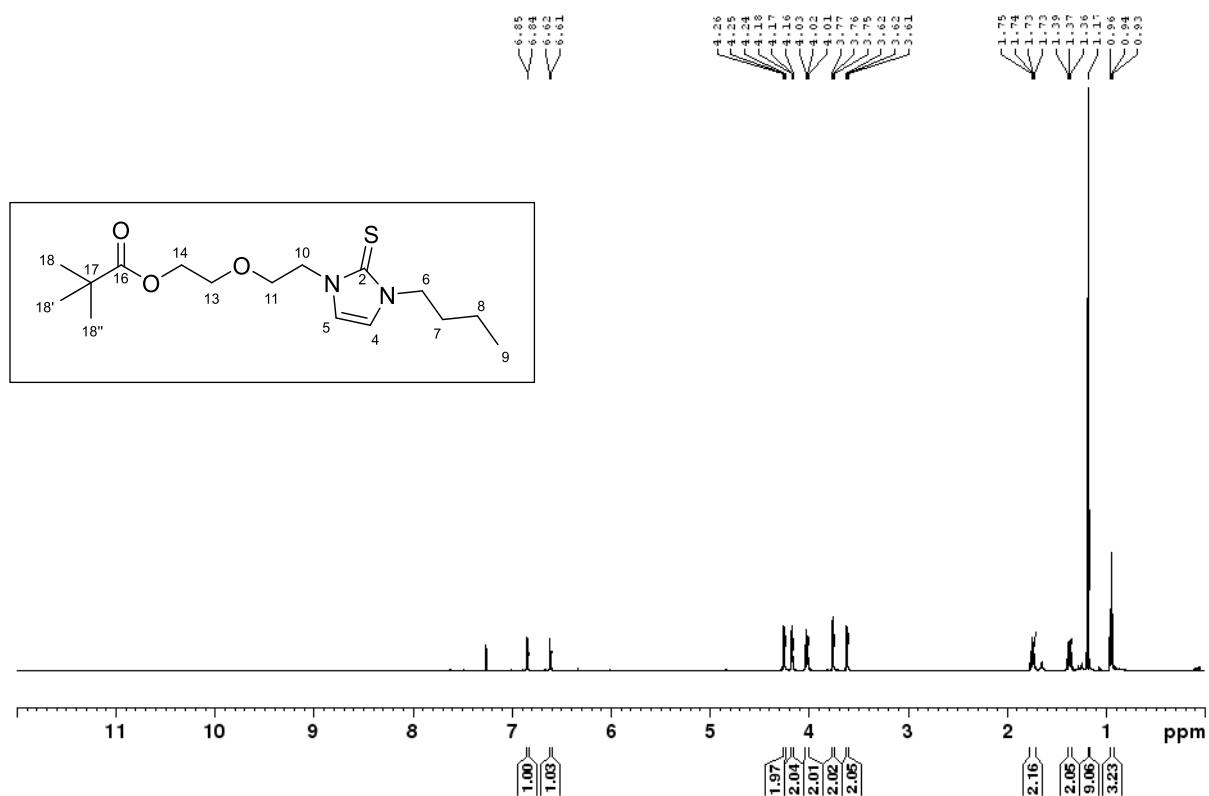


Figure 19: <sup>1</sup>H-NMR of 5a.

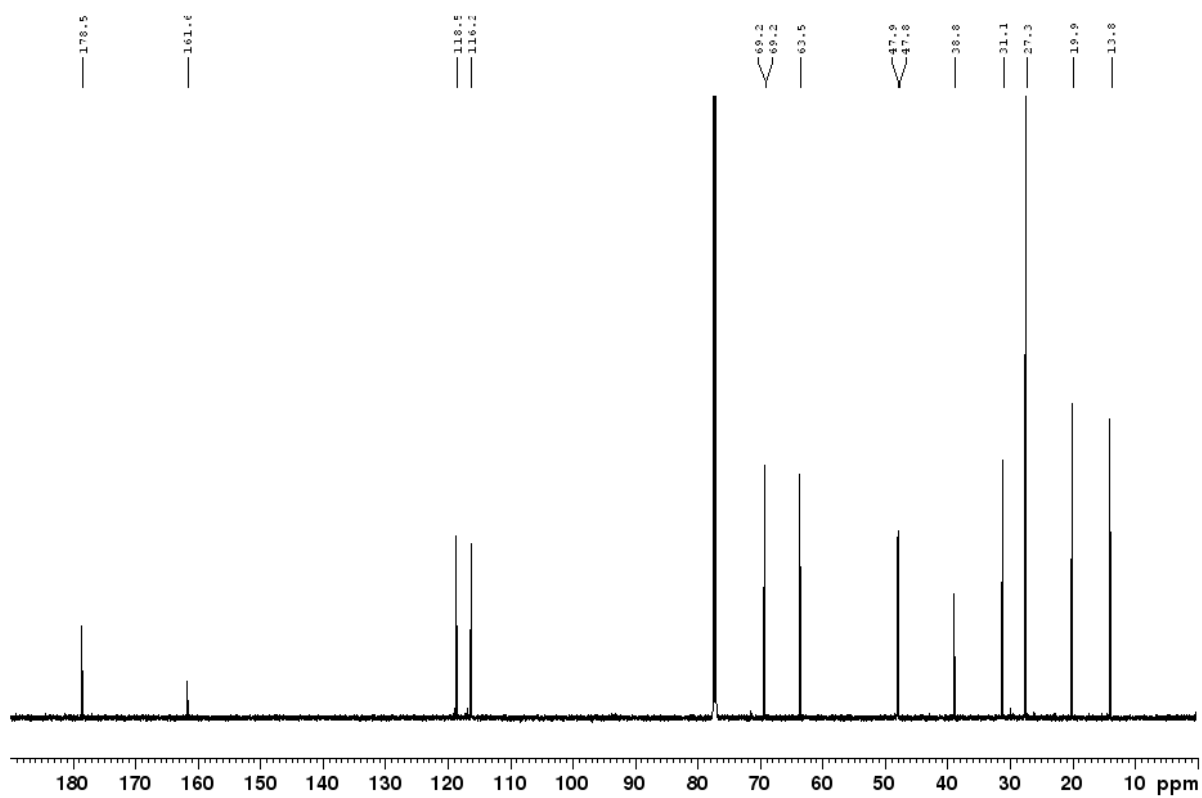


Figure 20: <sup>13</sup>C-NMR of 5a.

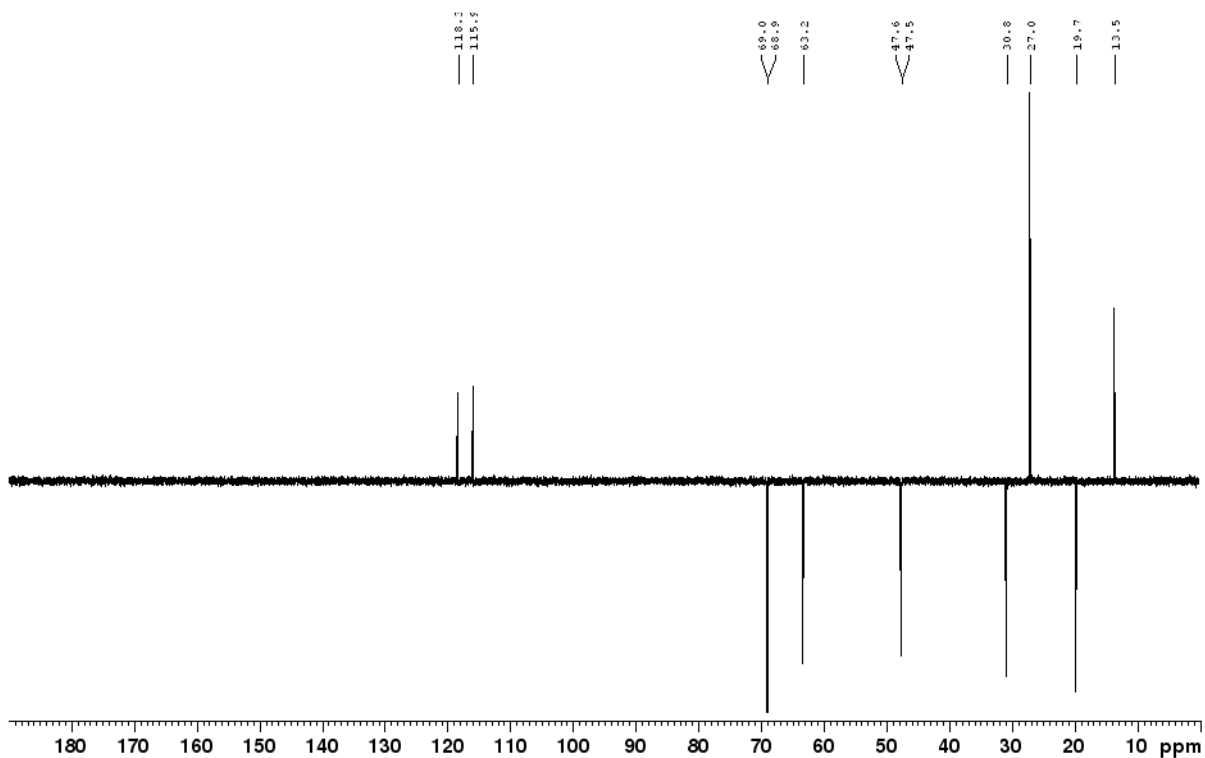


Figure 21: DEPT-135-spectrum of 5a.

## 8. NMR spectra of 5b

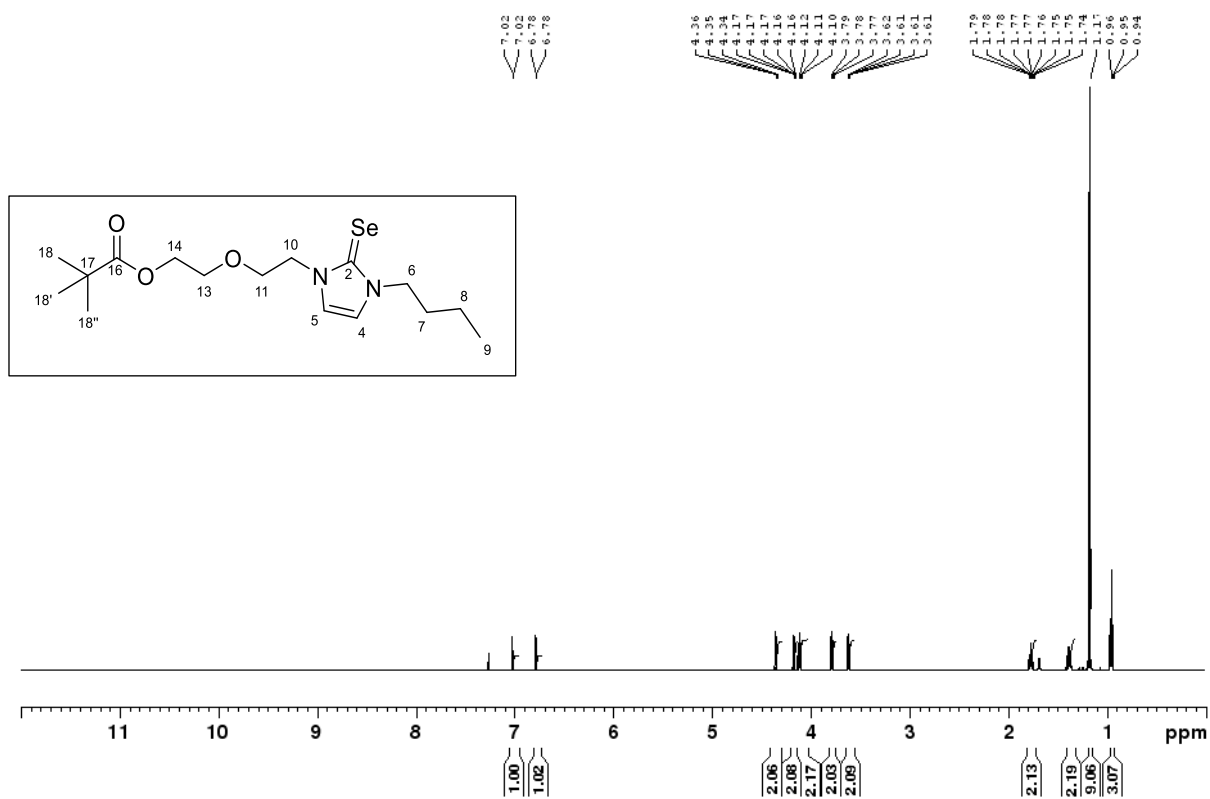


Figure 22: <sup>1</sup>H-NMR of 5b.

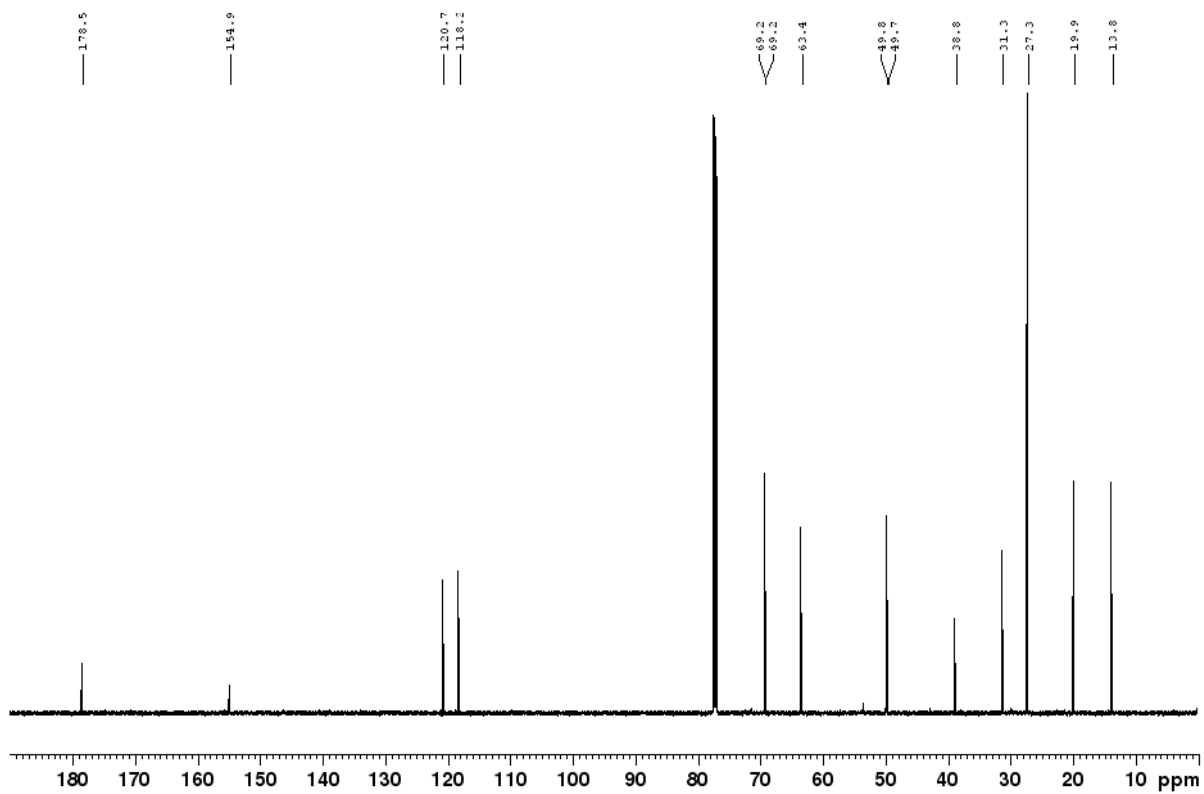


Figure 23:  $^{13}\text{C}$ -NMR of 5b.

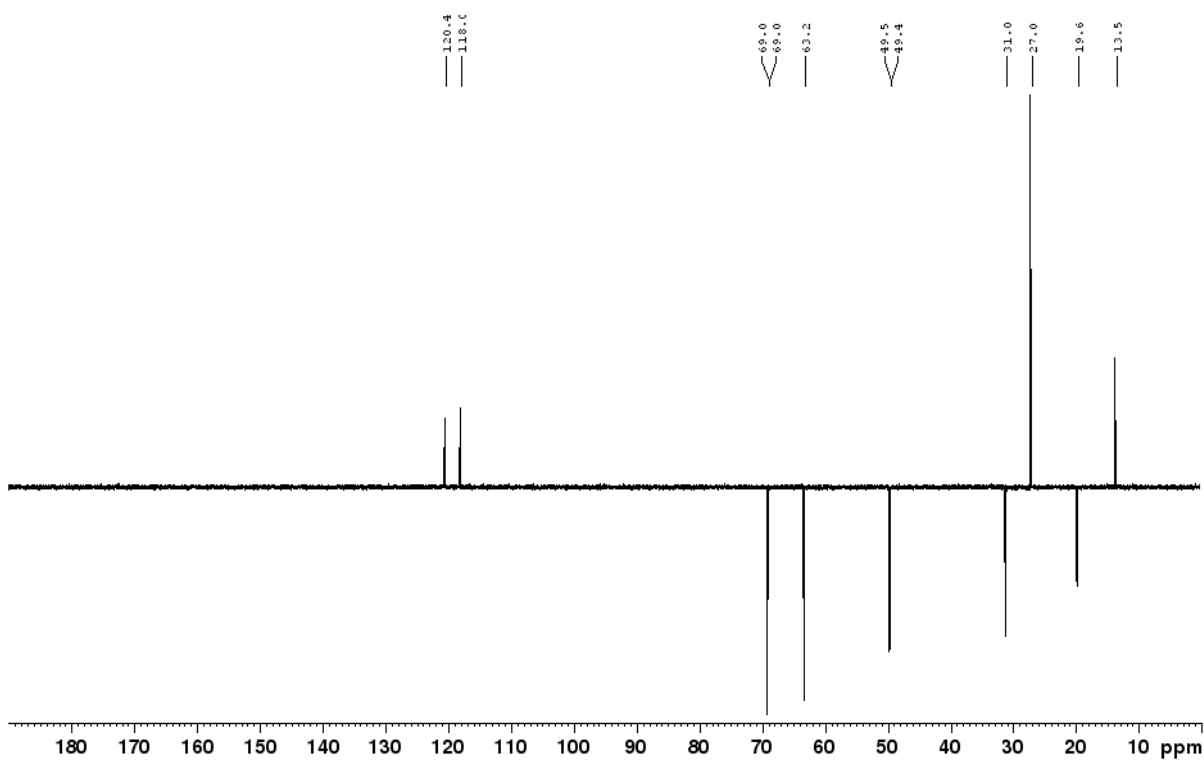


Figure 24: DEPT-135-spectrum of 5b.

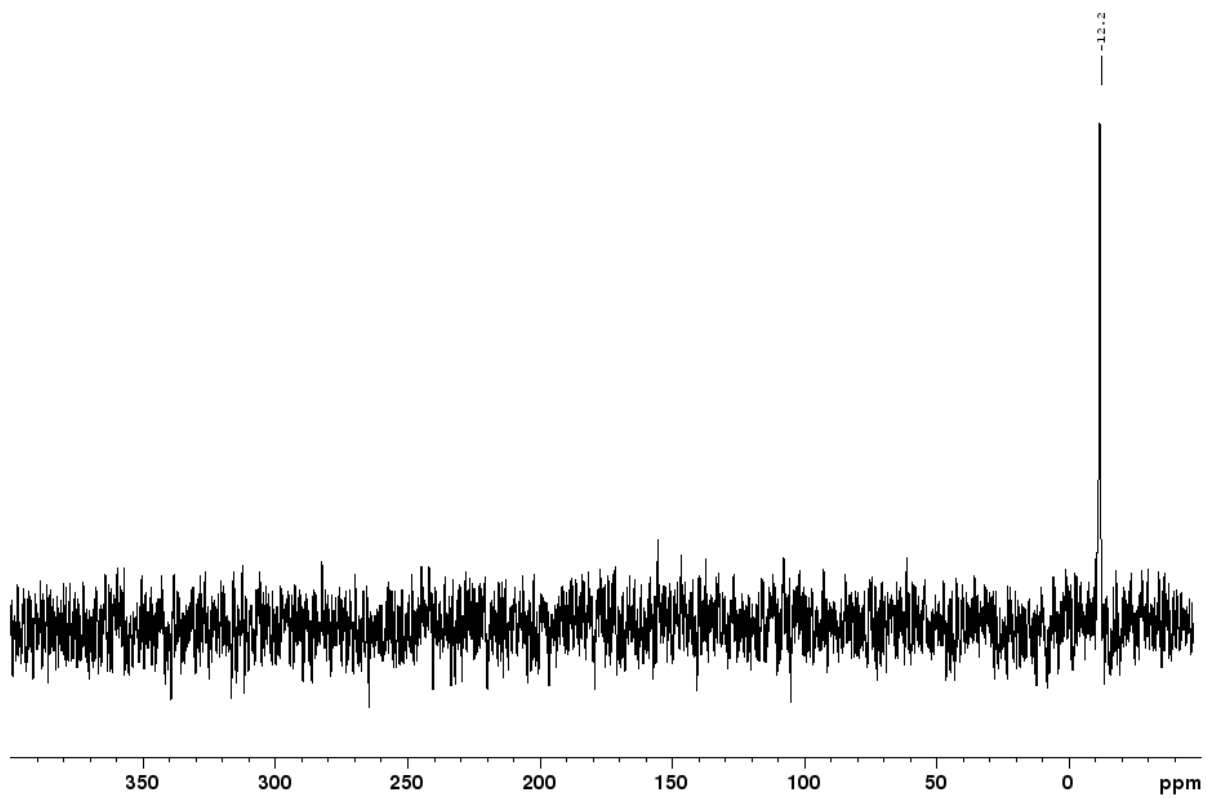


Figure 25:  $^{77}\text{Se}$ -NMR of 5b.

## 9. NMR spectra of 6a

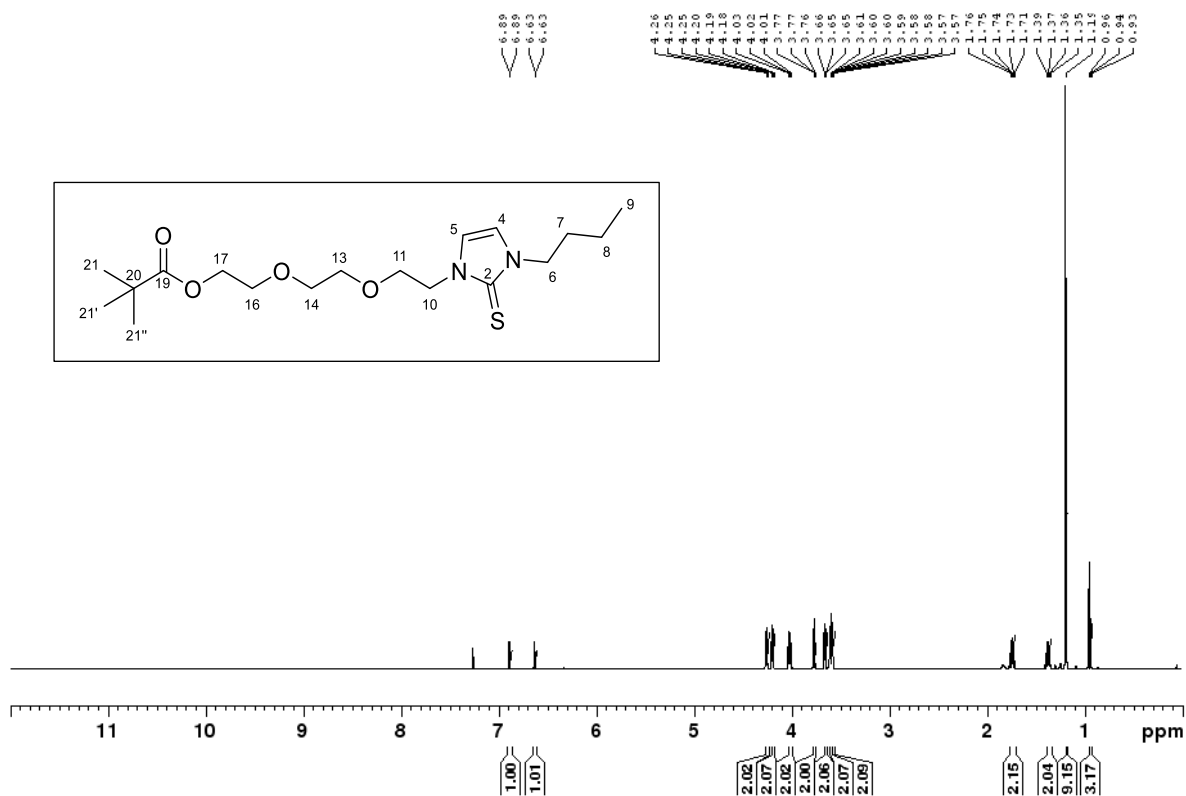


Figure 26: <sup>1</sup>H-NMR of 6a.

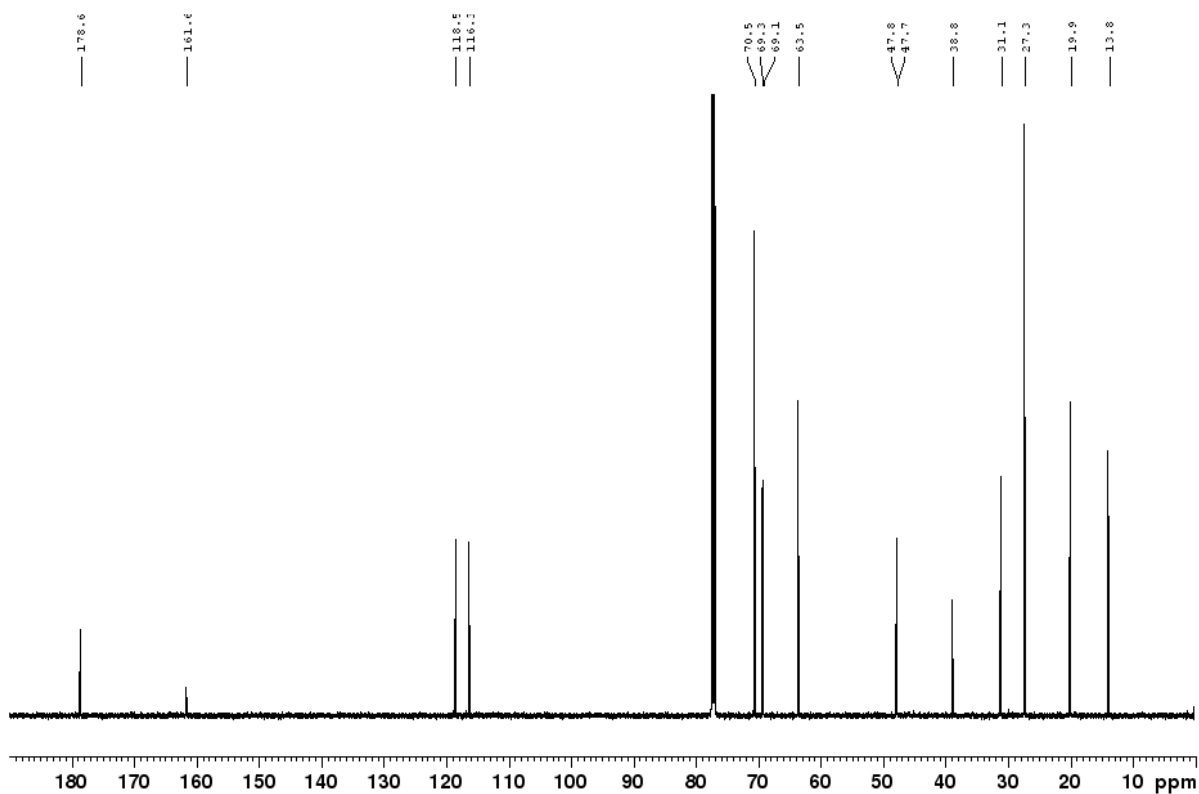


Figure 27: <sup>13</sup>C-NMR of 6a.

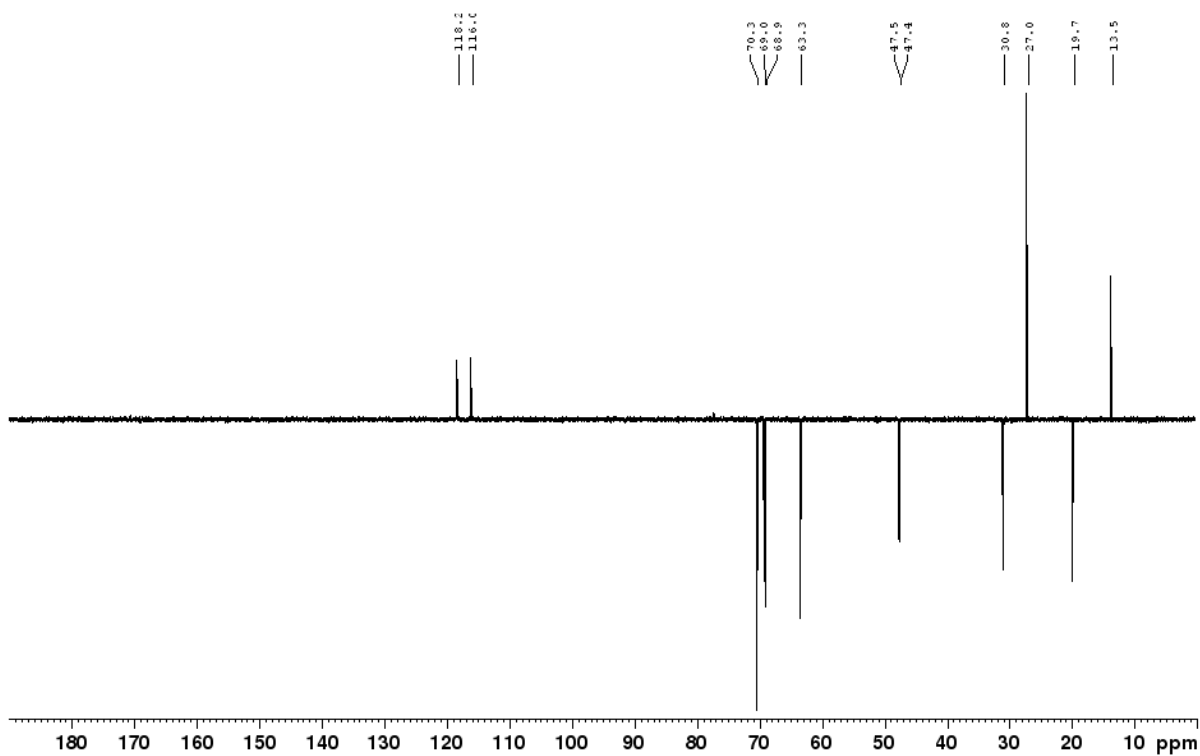


Figure 28: DEPT-135-spectrum of 6a.

## 10. NMR spectra of 6b

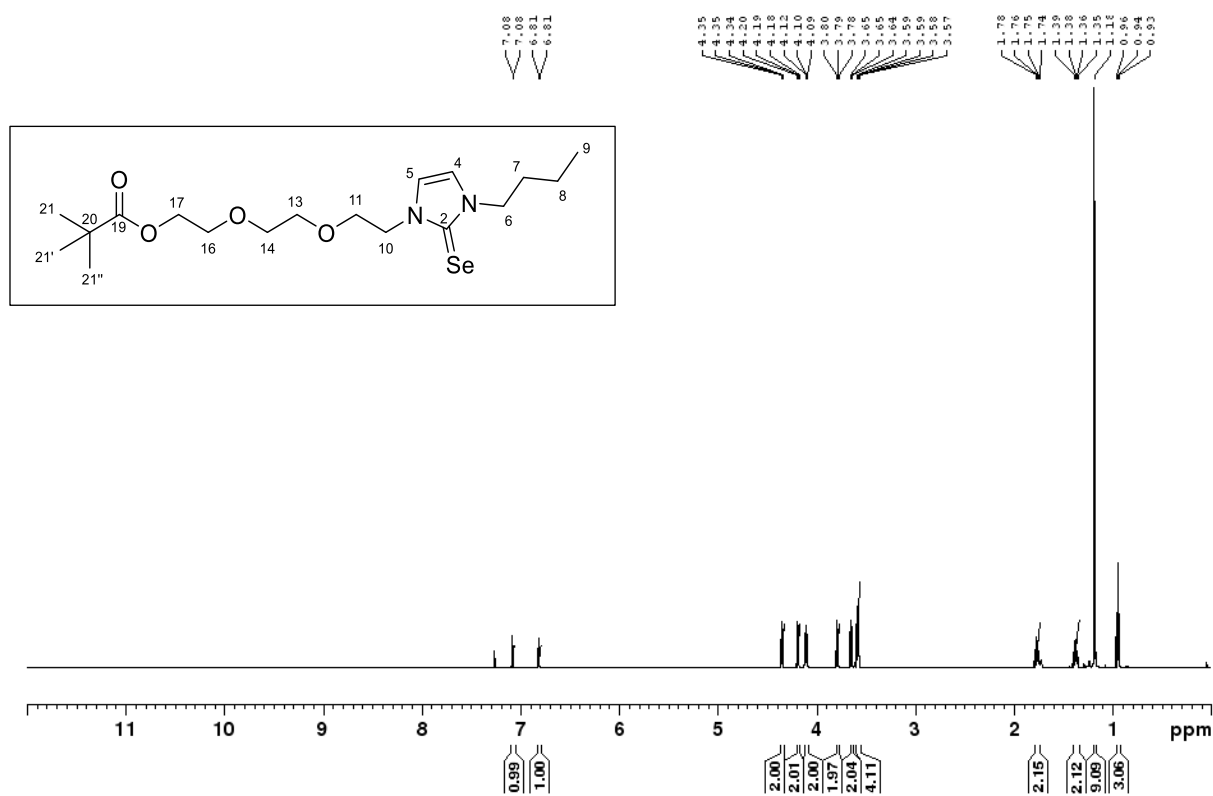


Figure 29:  $^1\text{H}$ -NMR of 6b.



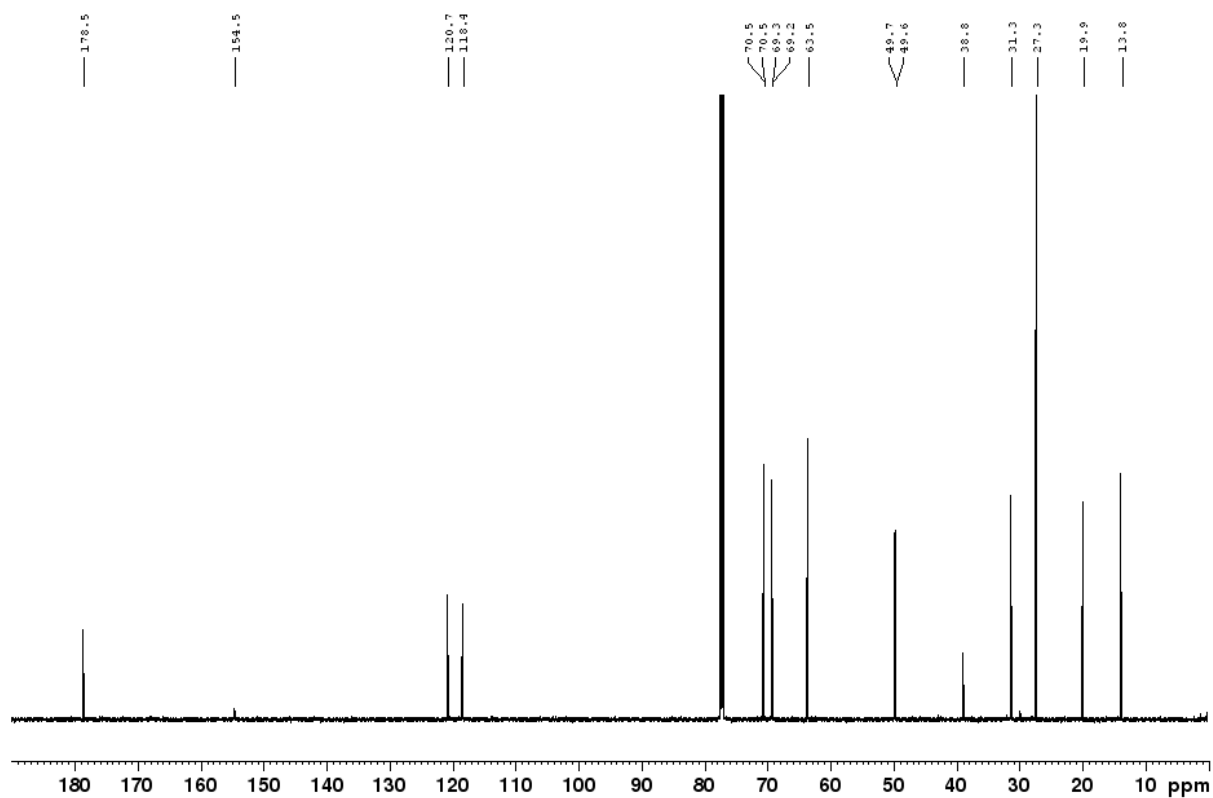


Figure 30:  $^{13}\text{C}$ -NMR of 6b.

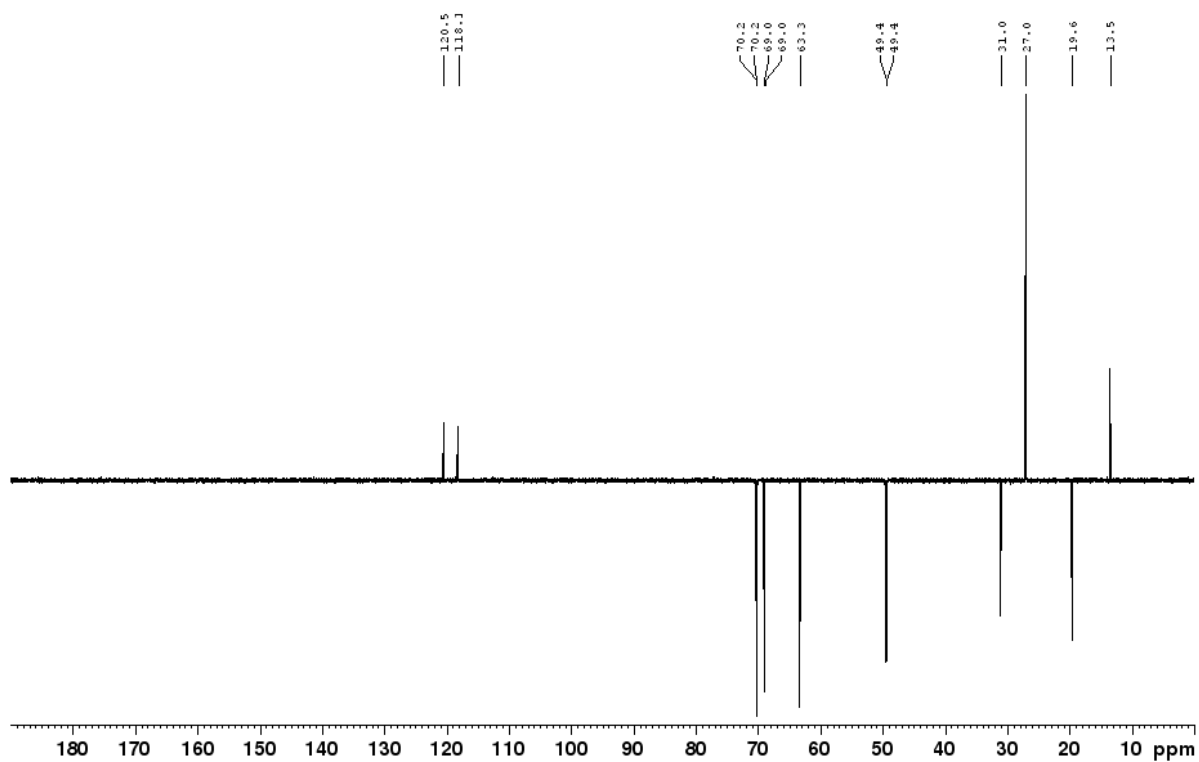


Figure 31: DEPT-135-spectrum of 6b.

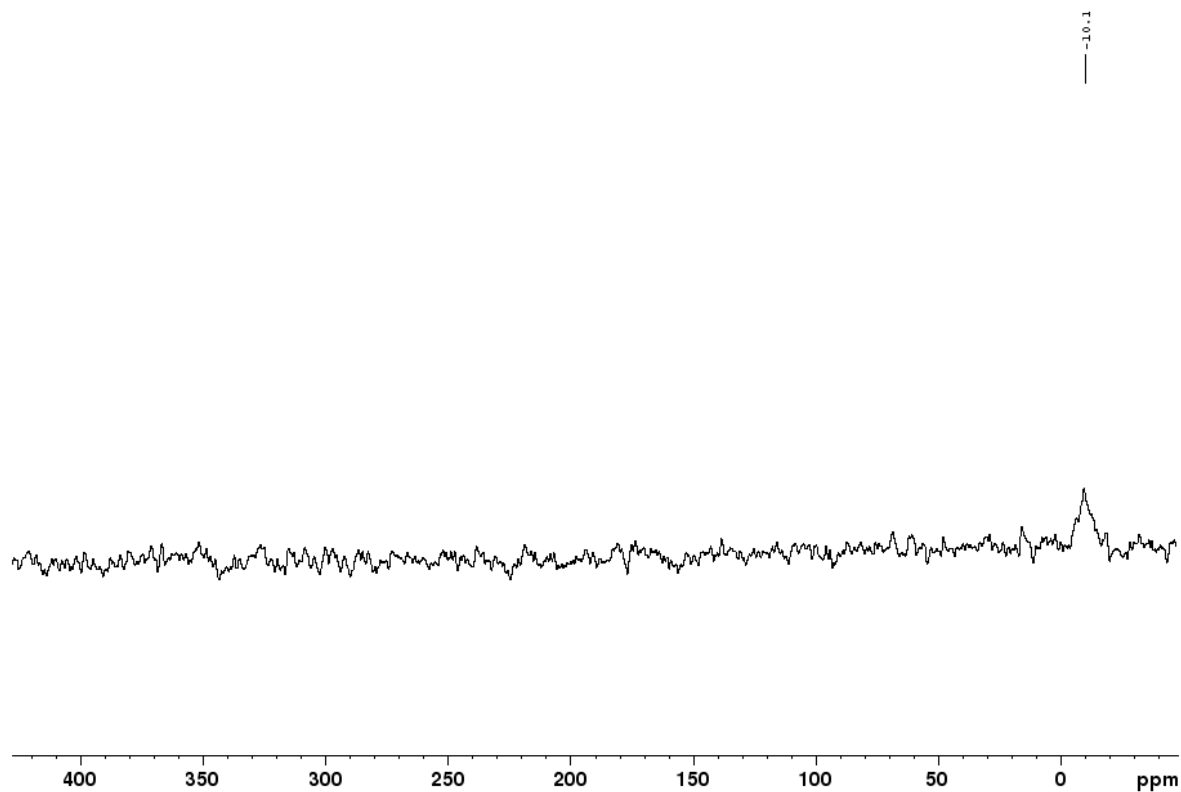


Figure 32:  $^{77}\text{Se}$ -NMR of 6b.

## 11. NMR spectra of 7a

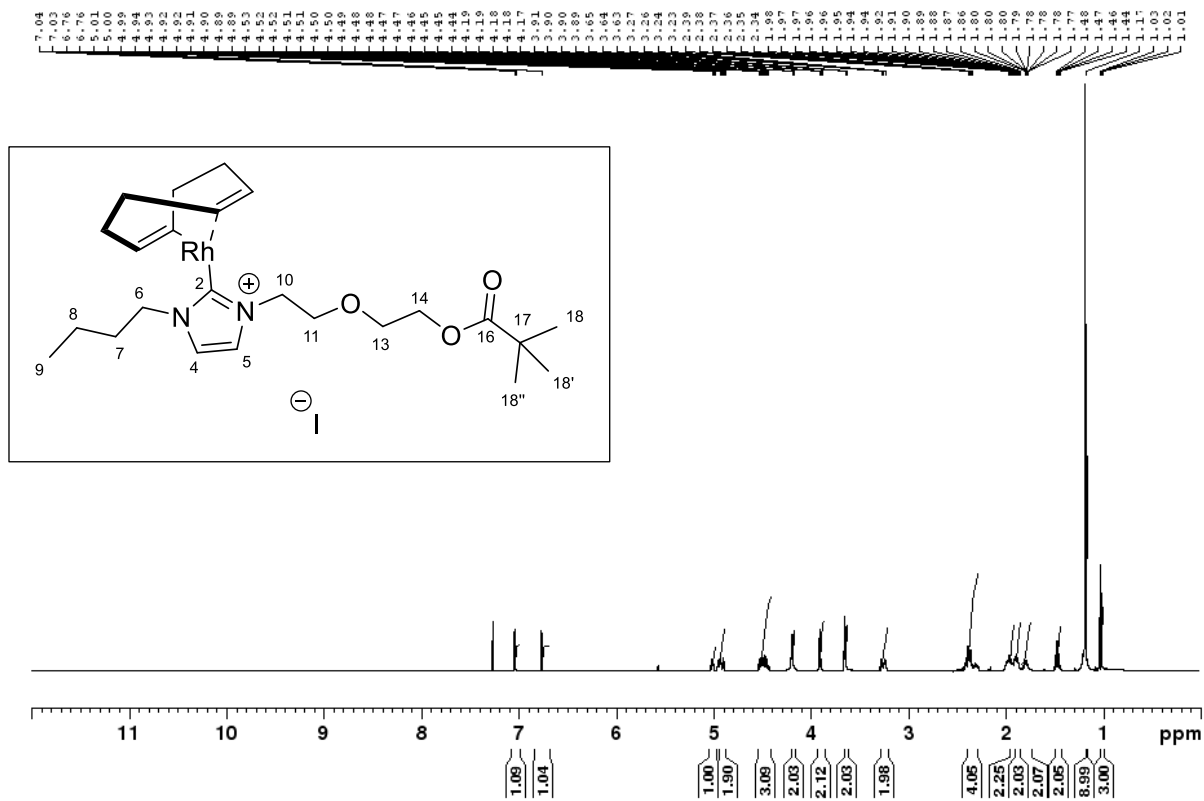


Figure 33:  $^1\text{H}$ -NMR of 7a.

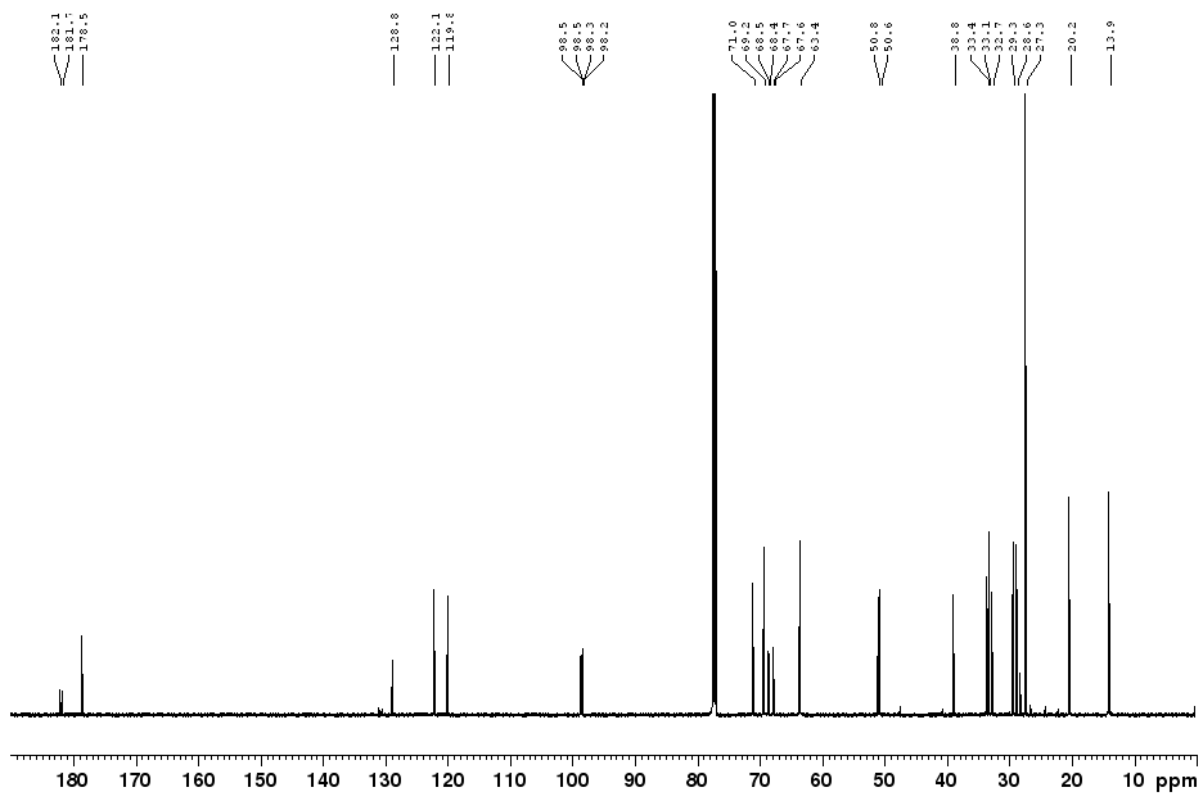


Figure 34:  $^{13}\text{C}$ -NMR of 7a.

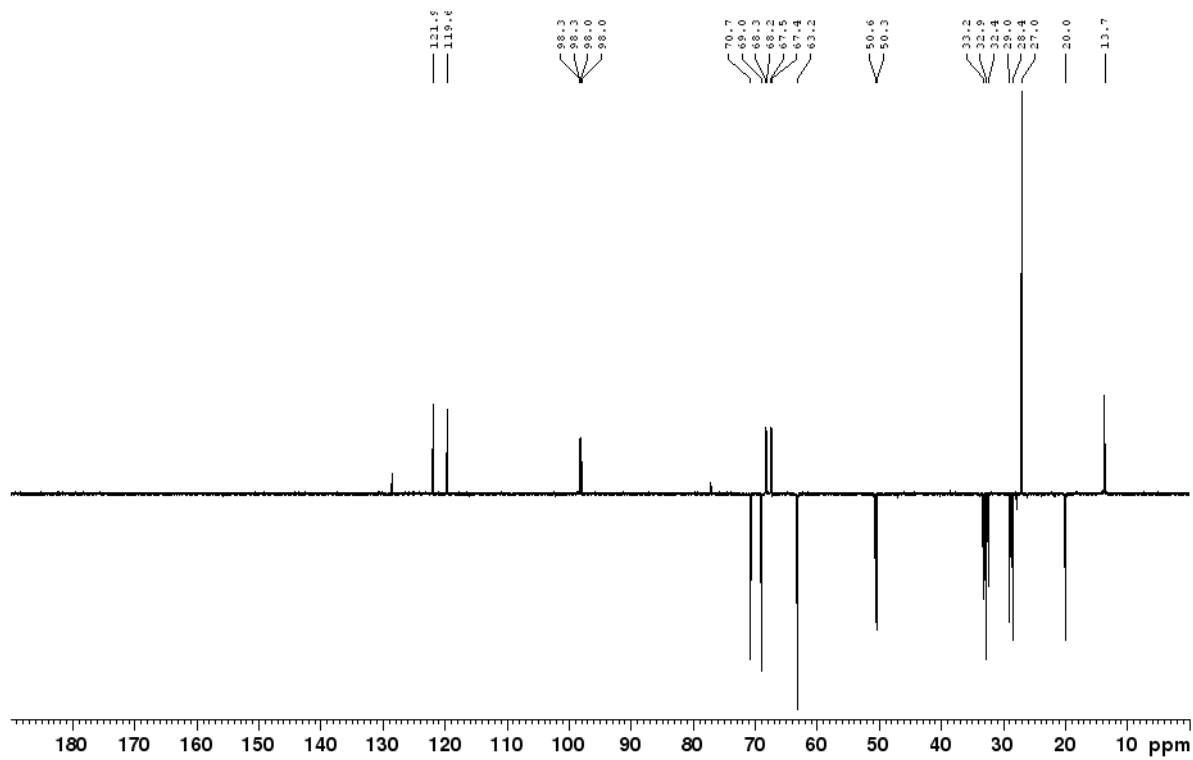


Figure 35: DEPT-135-spectrum of 7a.

## 12. NMR spectra of 7b

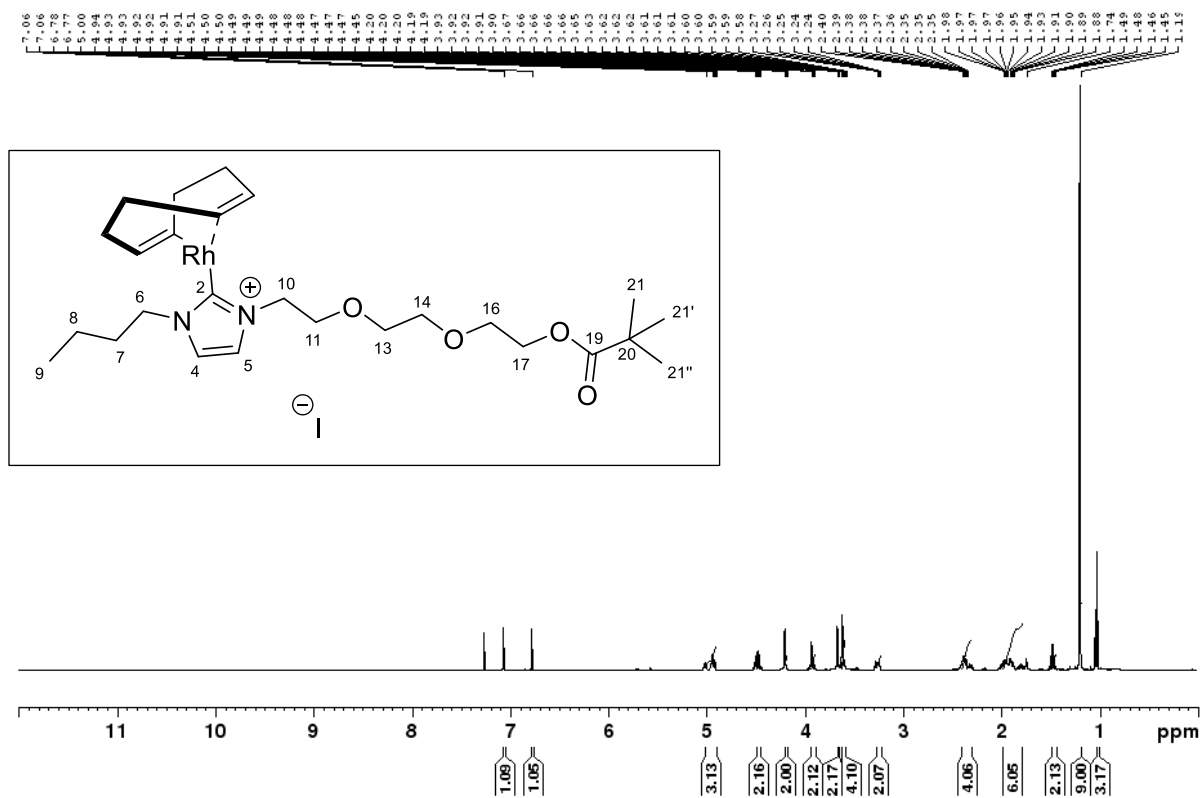


Figure 36: <sup>1</sup>H-NMR of 7b.

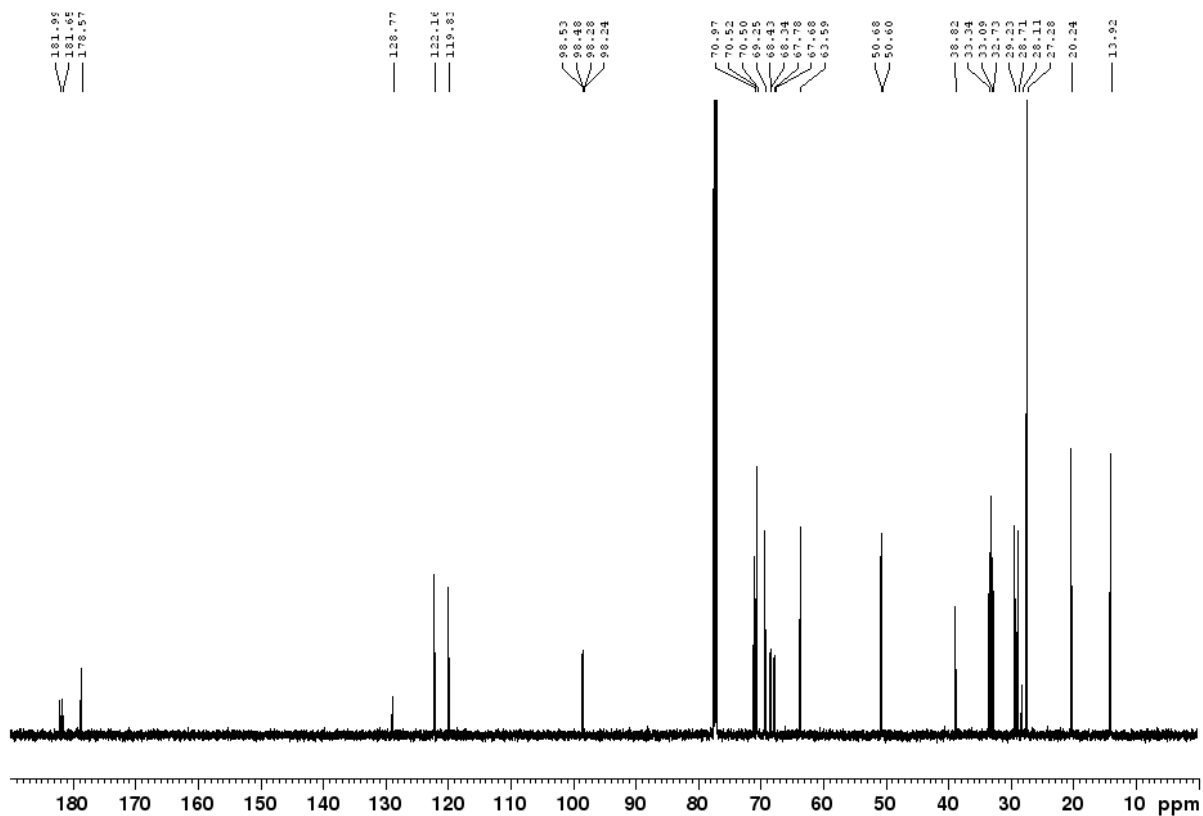


Figure 37: <sup>13</sup>C-NMR of 7b.

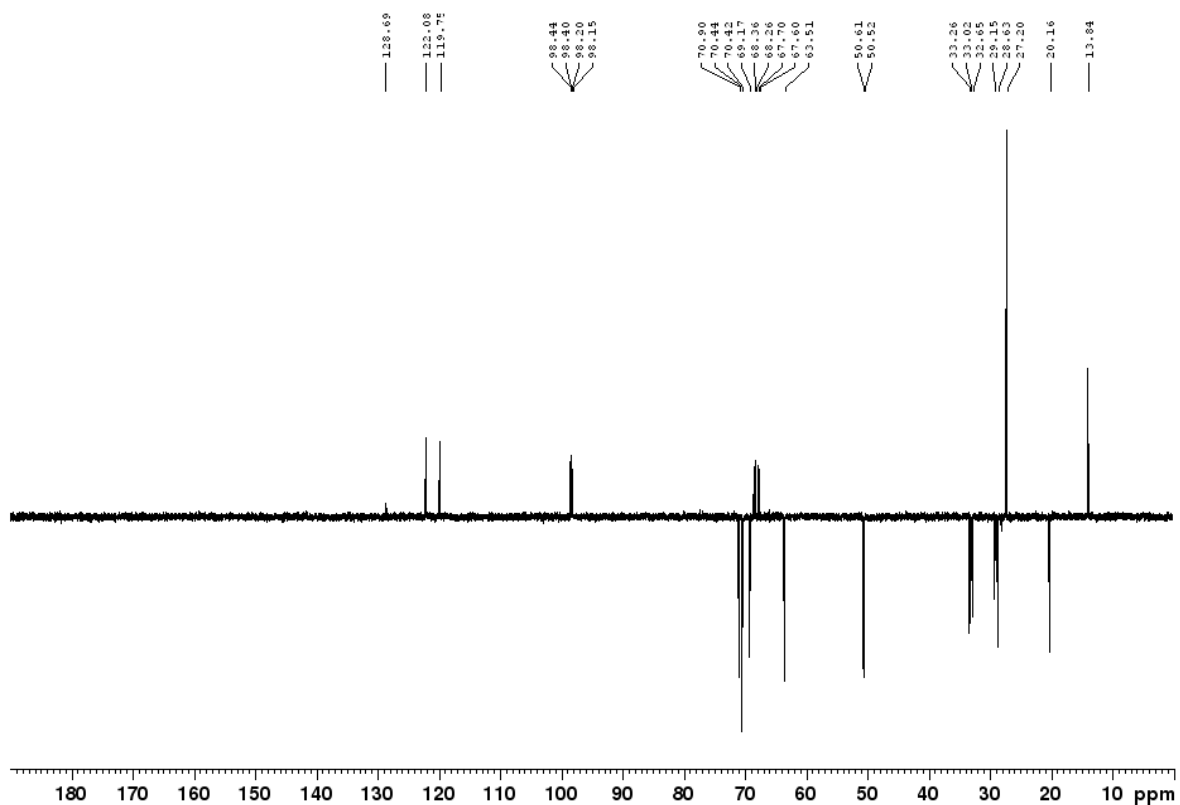


Figure 38: DEPT-135-spectrum of 7b.

### 13. NMR spectra of 8a

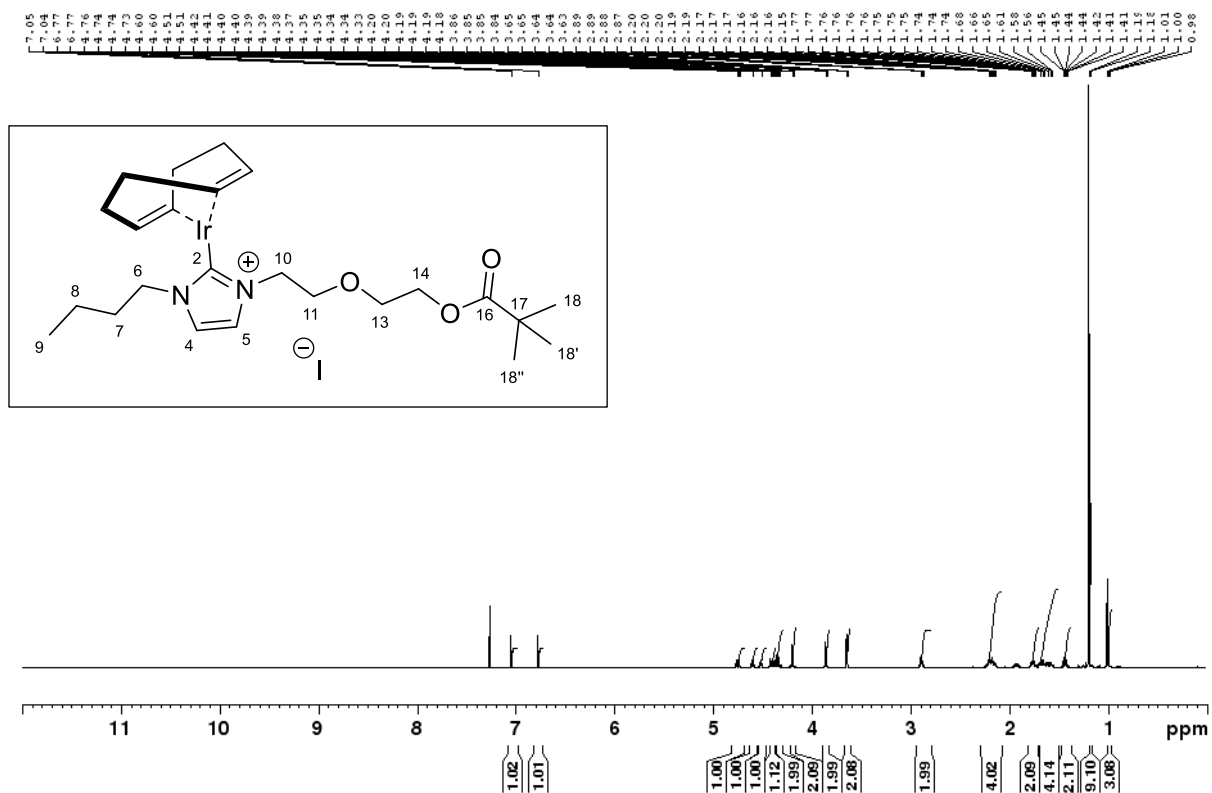


Figure 39:  $^1\text{H}$ -NMR of 8a.

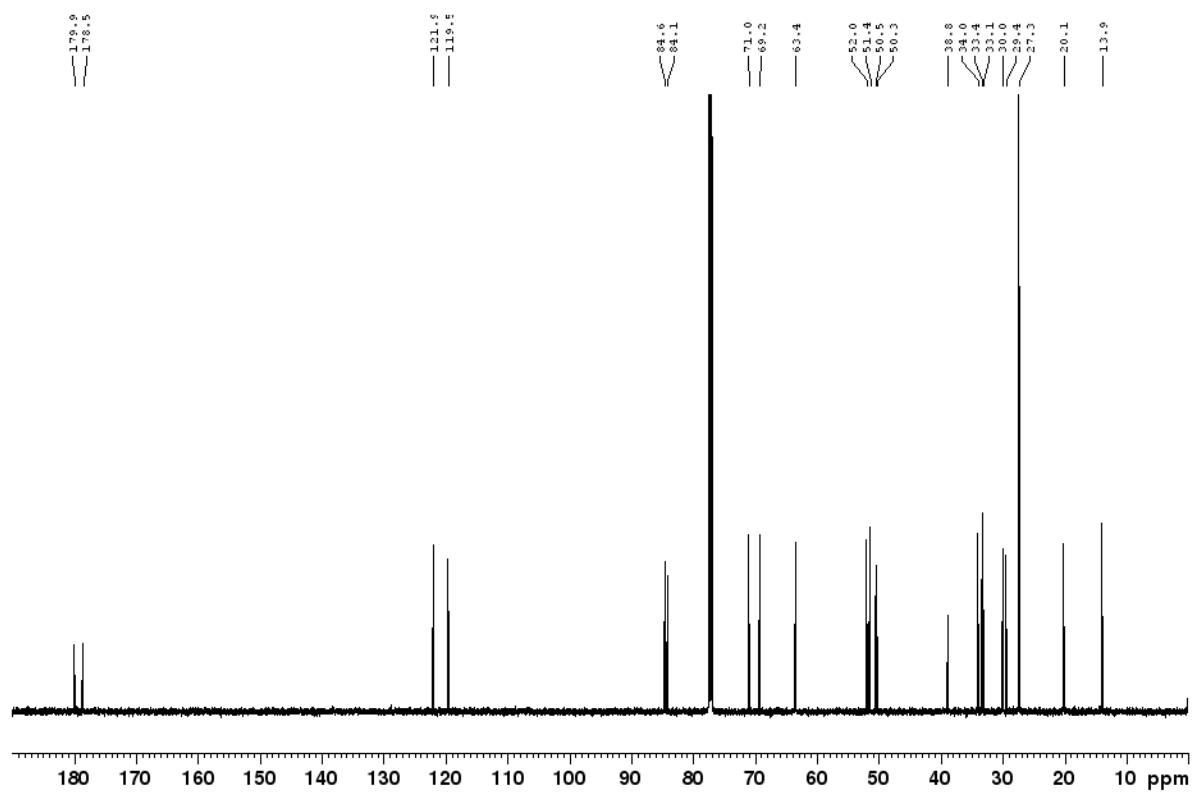


Figure 40:  $^{13}\text{C}$ -NMR of 8a.

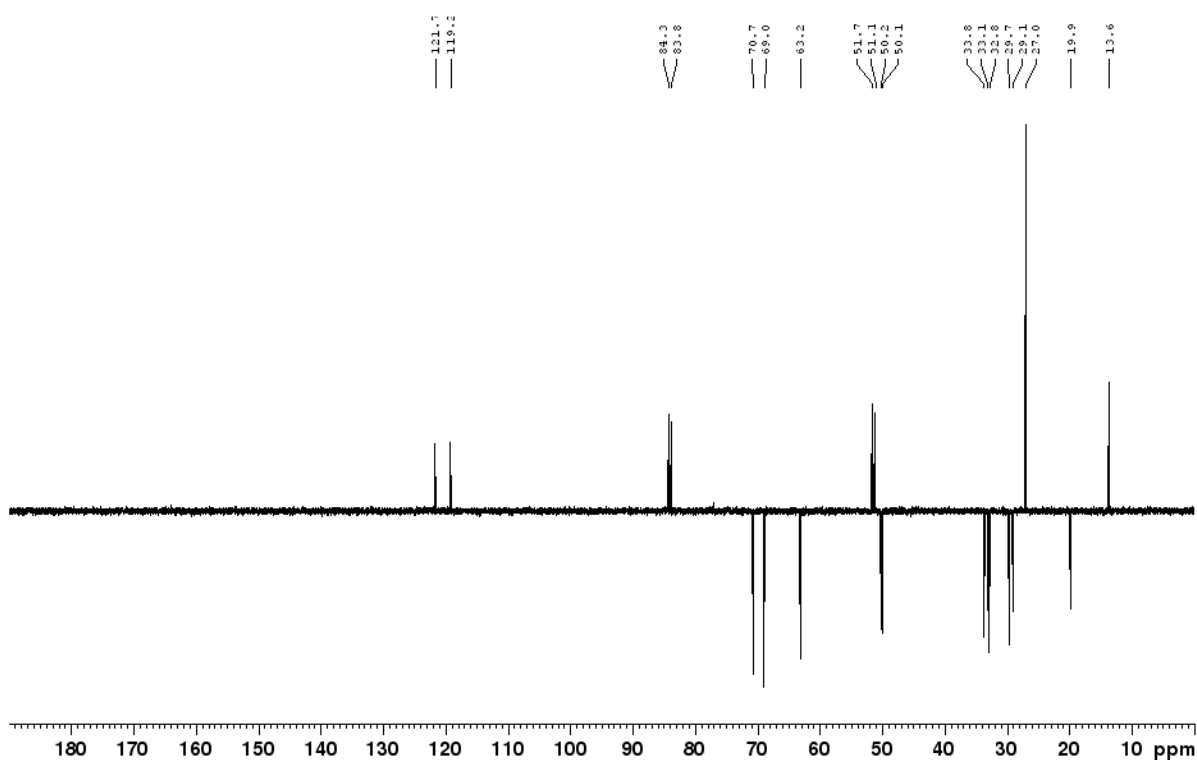


Figure 41: DEPT-135-spectrum of 8a.

## 14. NMR spectra of 8b

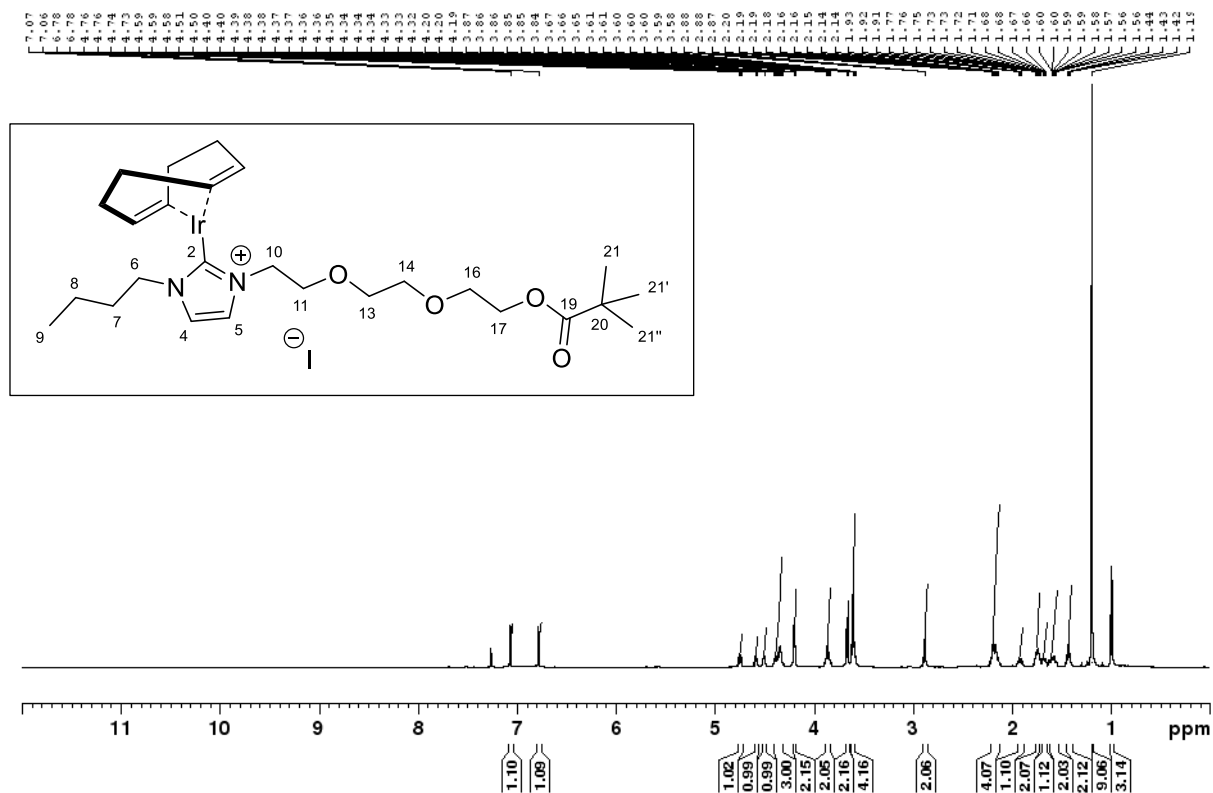


Figure 42: <sup>1</sup>H-NMR of 8b.

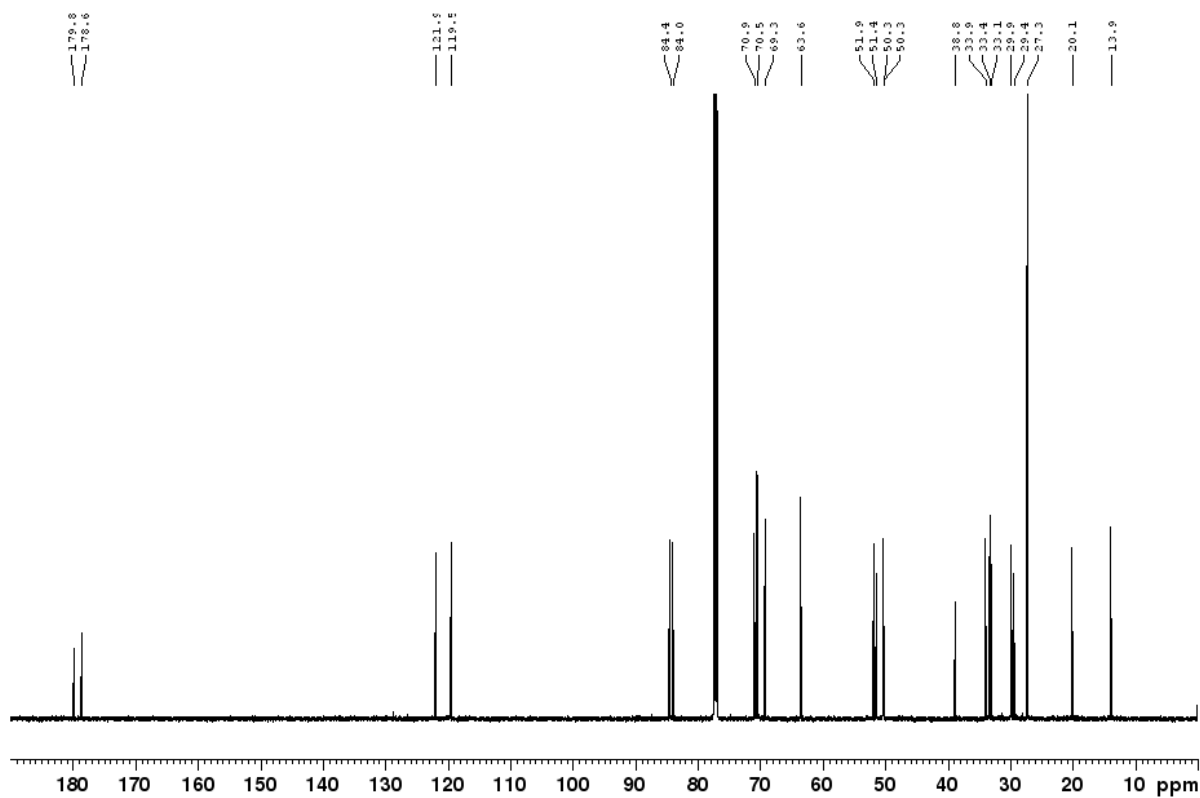


Figure 43: <sup>13</sup>C-NMR of 8b.

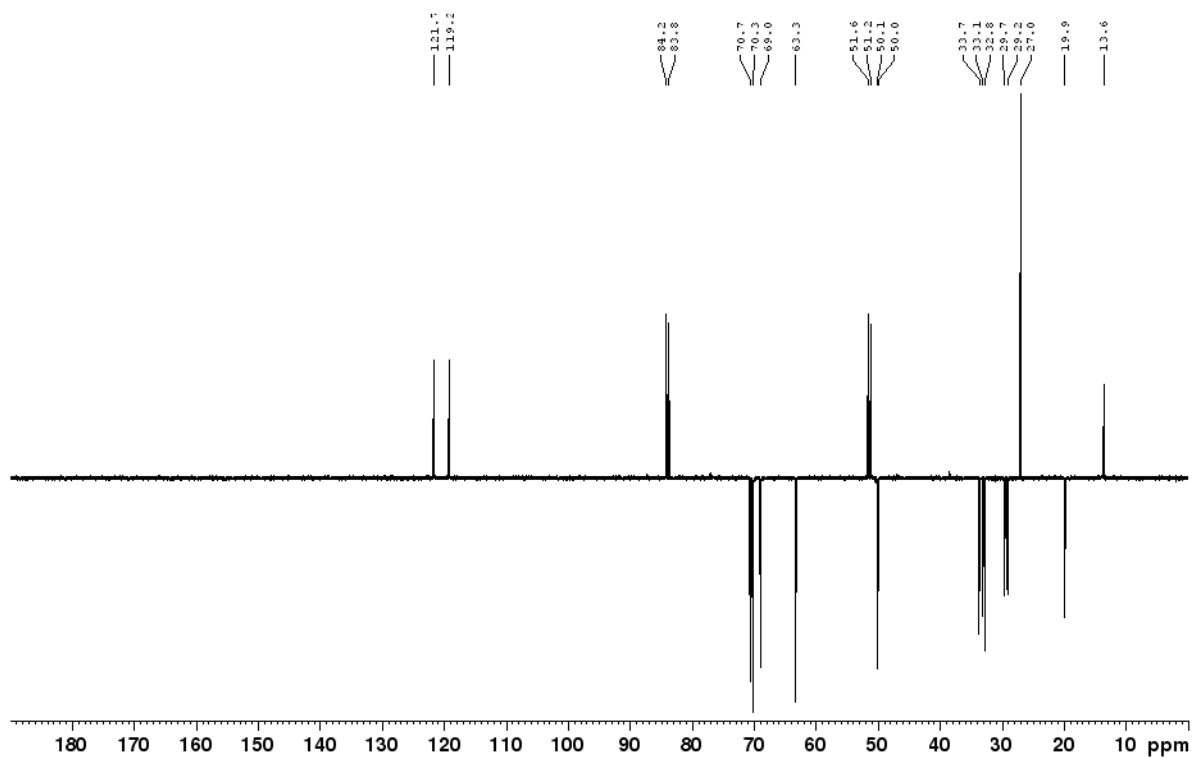


Figure 44: DEPT-135-spectrum of 8b.

## 15. NMR-Experiment for proof of carbene

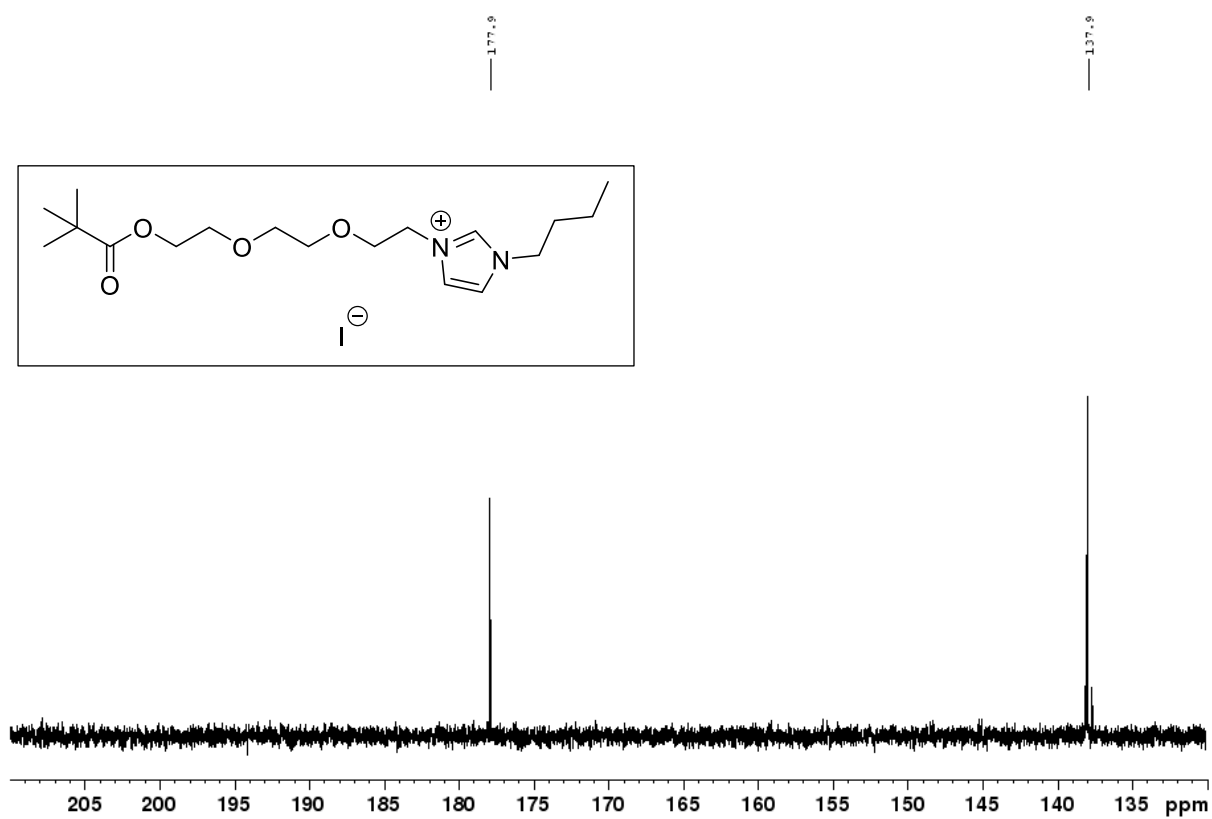


Figure 45:  $^{13}\text{C}$ -NMR of 4b.



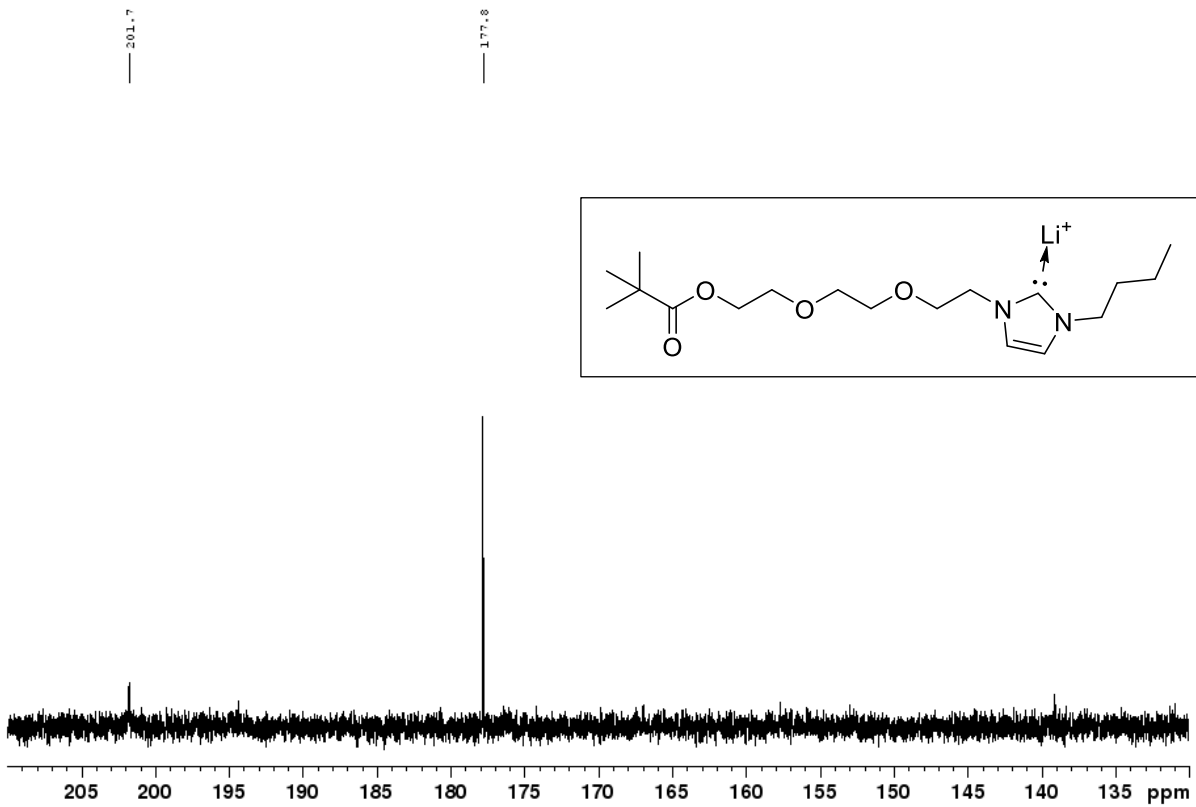


Figure 46:  $^{13}\text{C}$ -NMR of the carbene (4aA/4bA).

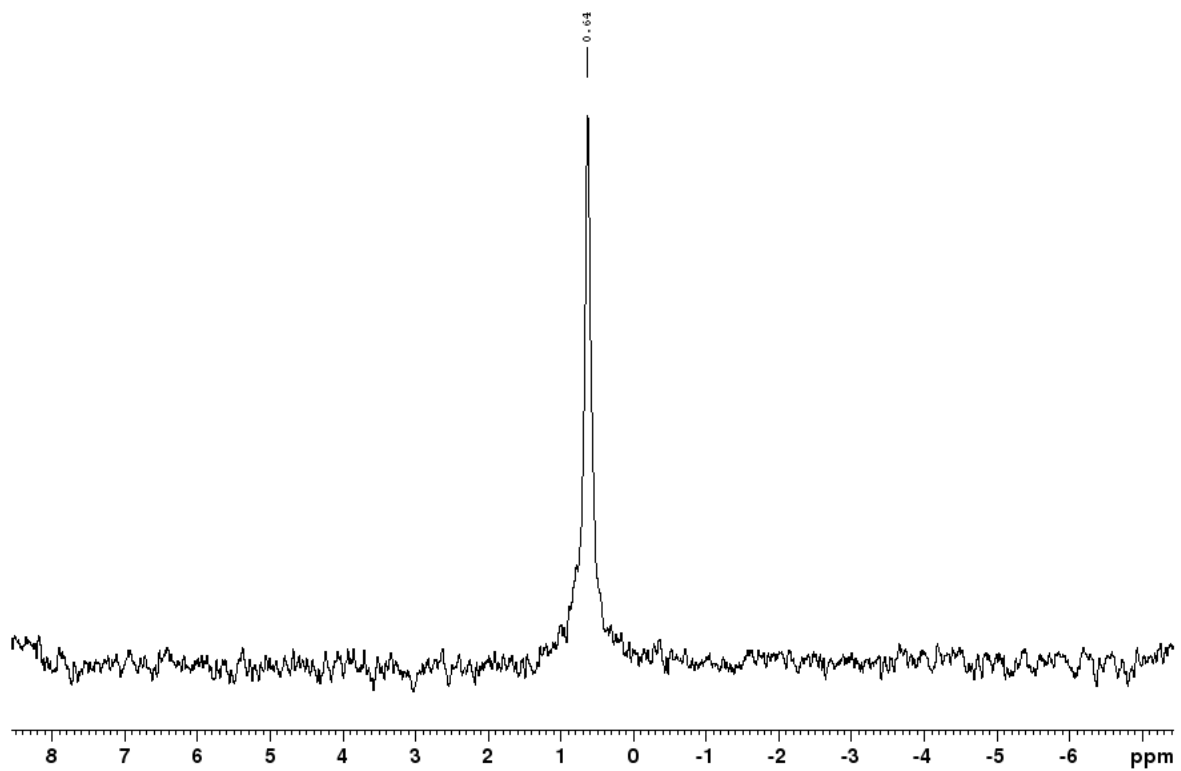


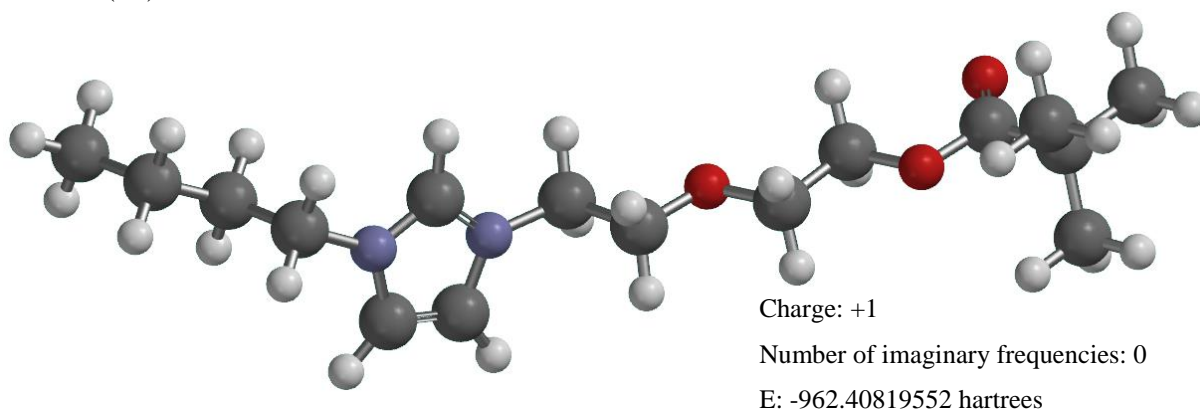
Figure 47:  $^7\text{Li}$ -NMR of the carbene (4aA/4bA).

## 16. HOMO/LUMO calculations

### DFT calculations (HOMO/LUMO coefficients and orbital energies, CREF value)

HOMO-LUMO DFT calculations were performed using the Spartan Software (*Spartan'20*, Wavefunction, Inc., Irvine, CA. Available from: <http://www.wavefun.com>) running on a MS Windows 10 Pro PC system with an AMD Ryzen Threadripper 3970X 32-Core and 128 GB. MMFF optimized structures were used as starting geometries for the geometry optimizations with the B3LYP density functional and the 6-311++G(d,p) basis set carried out as vacuum calculations. Subsequent frequency calculations of all final structures evidenced the absence of imaginary frequencies and thus the presence of true minima on the potential energy surface.

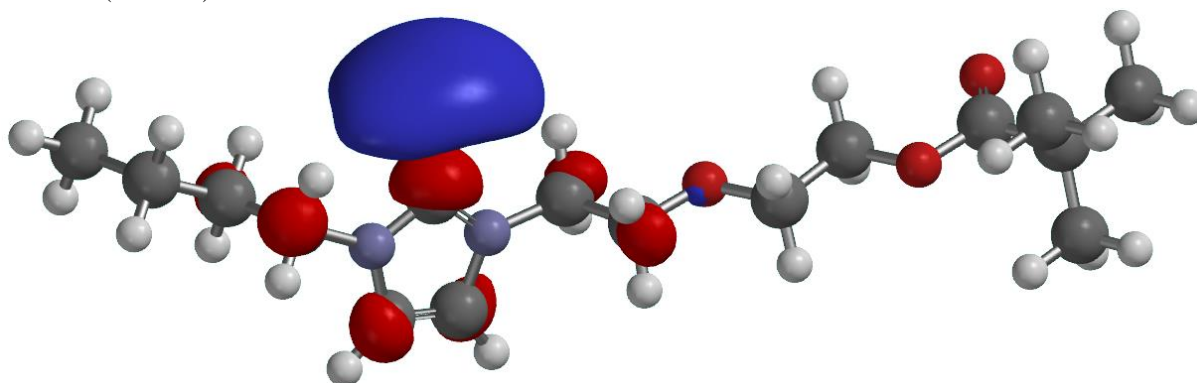
#### Cation (4a)



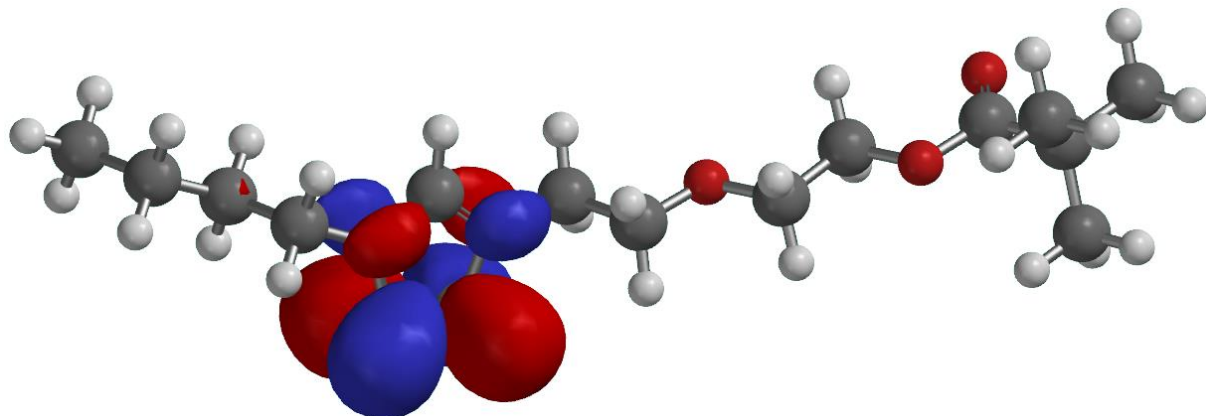
Coordinates (Angstroem)			
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C	-0.9345897382	-2.3621137318	3.9352374242
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C	0.8164252433	-1.3675879890	5.5006907347
C	0.0641949871	-0.8185155169	6.7146005323
C	0.9402180807	-0.8302654666	7.9741159738
C	0.2085952600	-0.2860065010	9.2036839026
C	-1.2713449896	0.0154622140	1.2003521087
C	-0.5052206383	-0.4939295410	-0.0236163575
O	-0.8679627092	0.3641678714	-1.0701063896
C	-0.2364626395	0.0663653076	-2.3188332670
C	-0.6963860307	1.1203930076	-3.3095535126
O	-0.0328167770	0.8164053277	-4.5442231489
C	-0.2769116005	1.6807294297	-5.5740703243
C	0.4718977182	1.2813758617	-6.8465424034
O	-1.0053813973	2.6303376518	-5.4412158534
C	0.1540451485	2.3032759078	-7.9484937671
C	0.0112484671	-0.1277622921	-7.2816570063
C	1.9896628191	1.2688294817	-6.5574914587
H	-1.0898402418	-3.2374885713	4.5430131025

H	-2.2827998720	-2.4507199465	2.1729434624
H	0.5460361055	0.4619040325	3.3340978434
H	1.1518394360	-2.3923977926	5.6692664444
H	1.7002252691	-0.7676506879	5.2752473127
H	-0.8380778722	-1.4162177647	6.8864448381
H	-0.2697086383	0.2032423108	6.5015947256
H	1.2779524182	-1.8541040932	8.1715946441
H	1.8444323689	-0.2369991815	7.7938455175
H	0.8615170720	-0.2971078400	10.0785587640
H	-0.1196012738	0.7455630829	9.0479808388
H	-0.6737208908	-0.8872064991	9.4413835457
H	-1.0166399611	1.0578698839	1.3916591312
H	-2.3461957130	-0.0408054556	1.0289026145
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H	-0.4234173714	2.1217599490	-2.9702228056
H	-1.7794335716	1.0899635401	-3.4456505676
H	0.4629798648	3.3100091628	-7.6611243593
H	-0.9152997639	2.3348330594	-8.1656312208
H	0.6840879775	2.0272315829	-8.8635132149
H	0.5234401183	-0.4049857570	-8.2065136296
H	-1.0648532315	-0.1519964291	-7.4745430075
H	0.2444358542	-0.8771130808	-6.5232117466
H	2.3387446876	2.2509589485	-6.2264210929
H	2.2459527711	0.5338200790	-5.7925403811
H	2.5289080144	1.0141694543	-7.4735796921

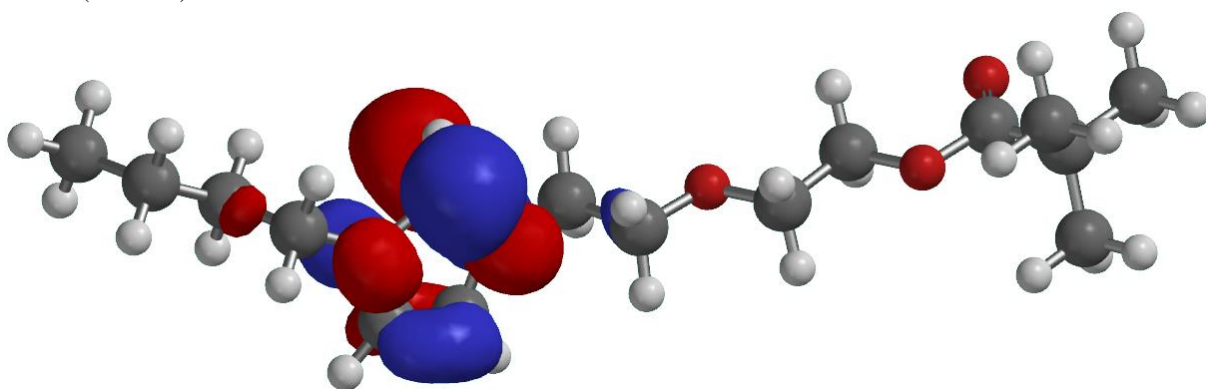
LUMO+2 (-3.53 eV)



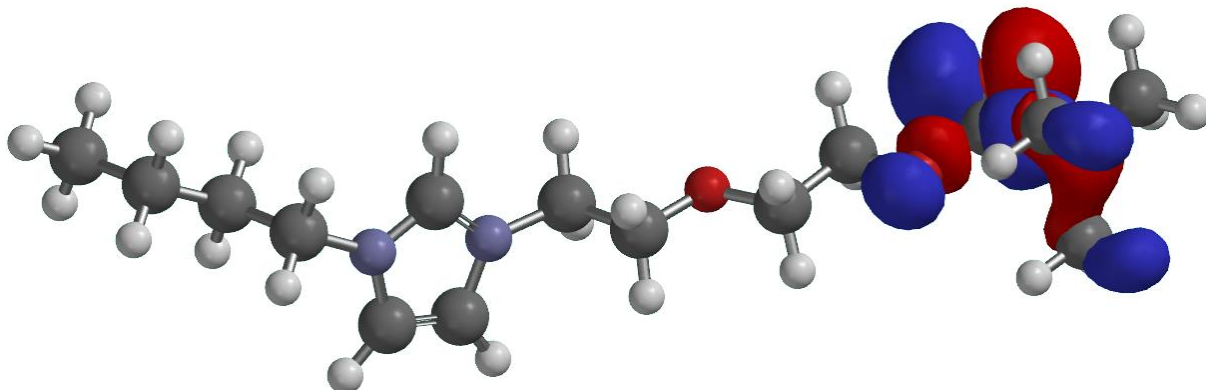
LUMO+1 (-4.14 eV)



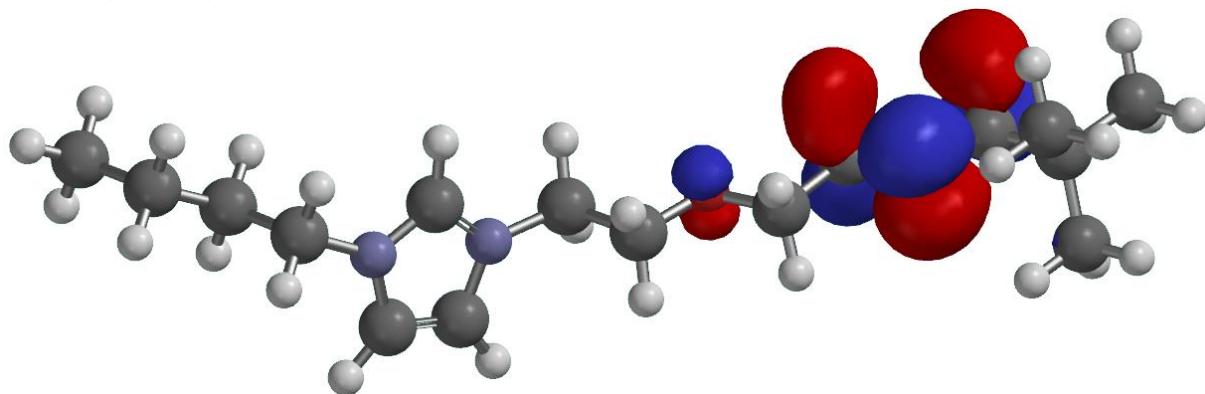
LUMO (-5.10 eV)



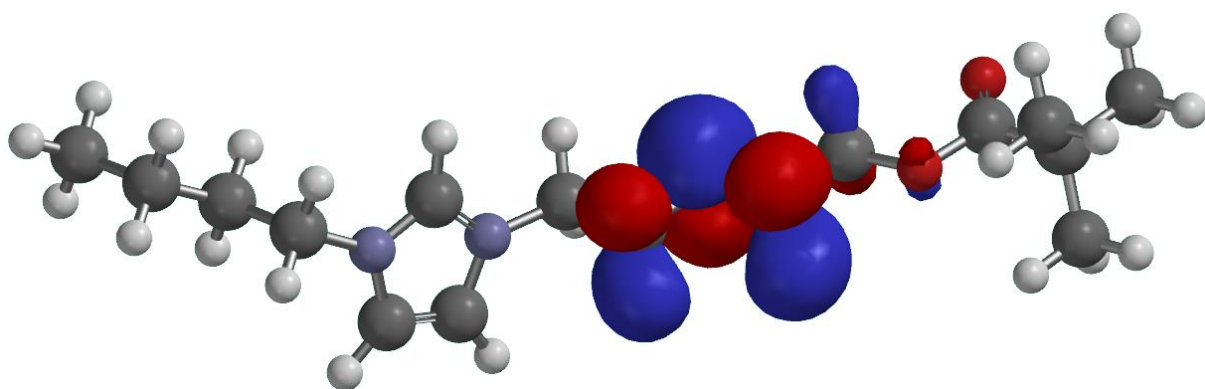
HOMO (-9.34 eV)



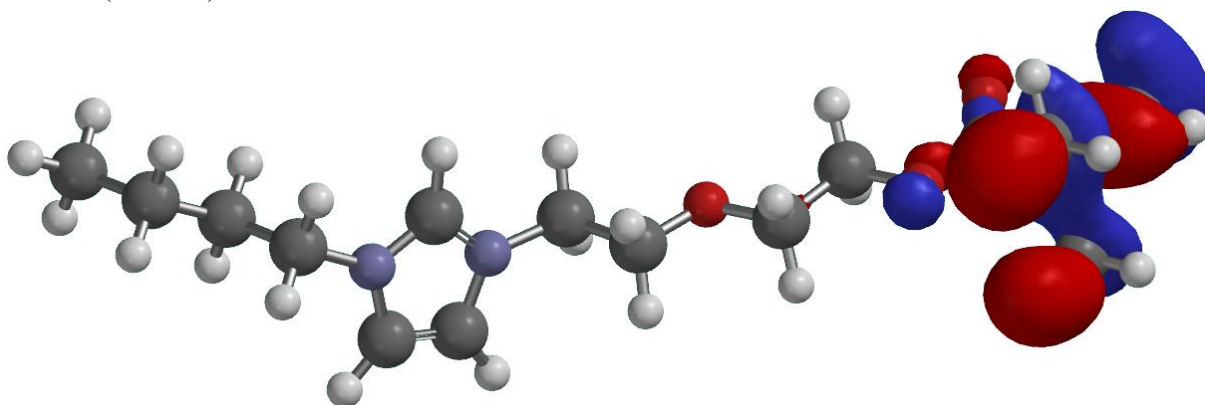
HOMO-1 (-10.37 eV)



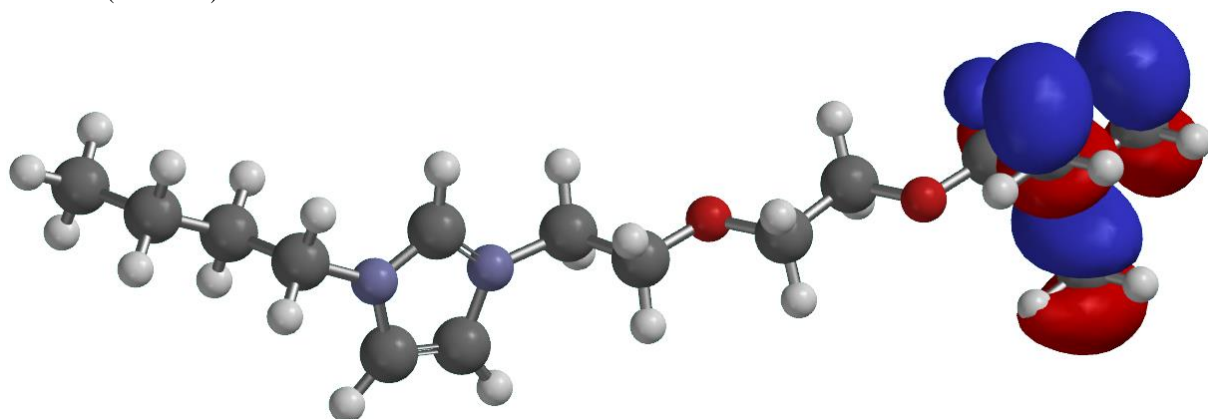
HOMO-2 (-10.59 eV)



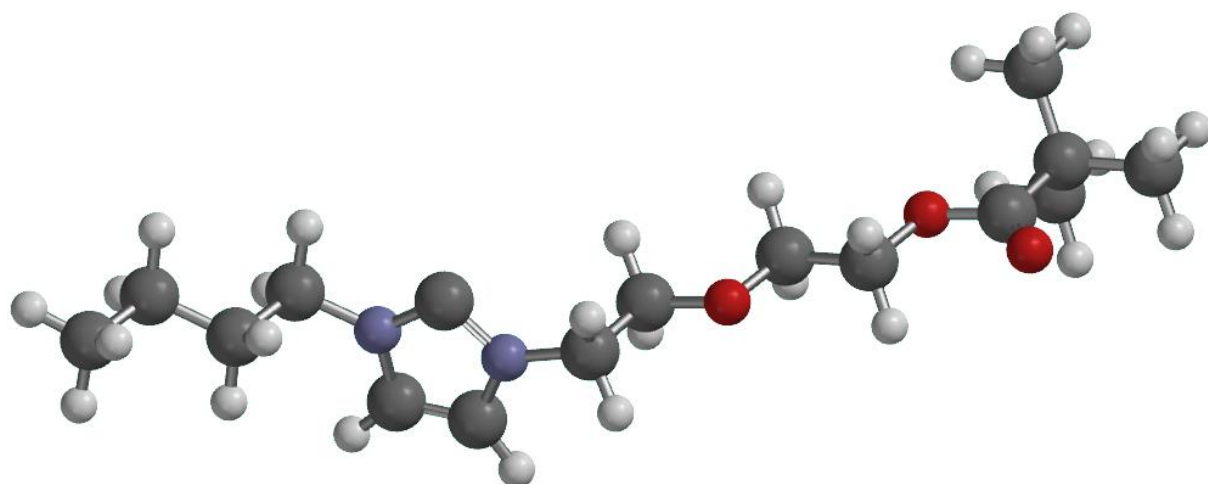
HOMO-3 (-10.80 eV)



HOMO-4 (-10.80 eV)



**Carbene (4aA) from the cation (4a)**



Charge: 0

Number of imaginary frequencies: 0

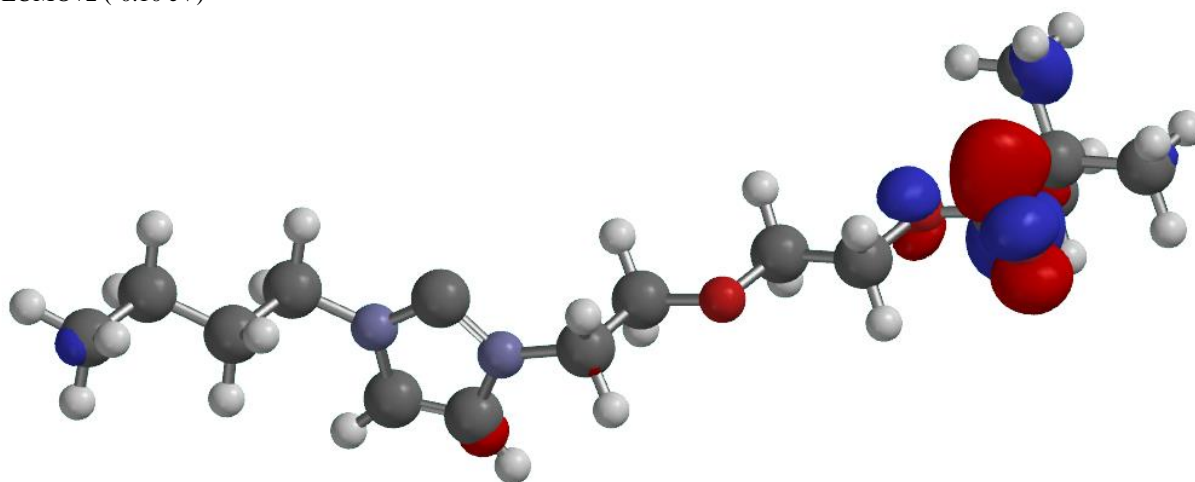
E: -961.97805795 hartrees

Coordinates (Angstroem)

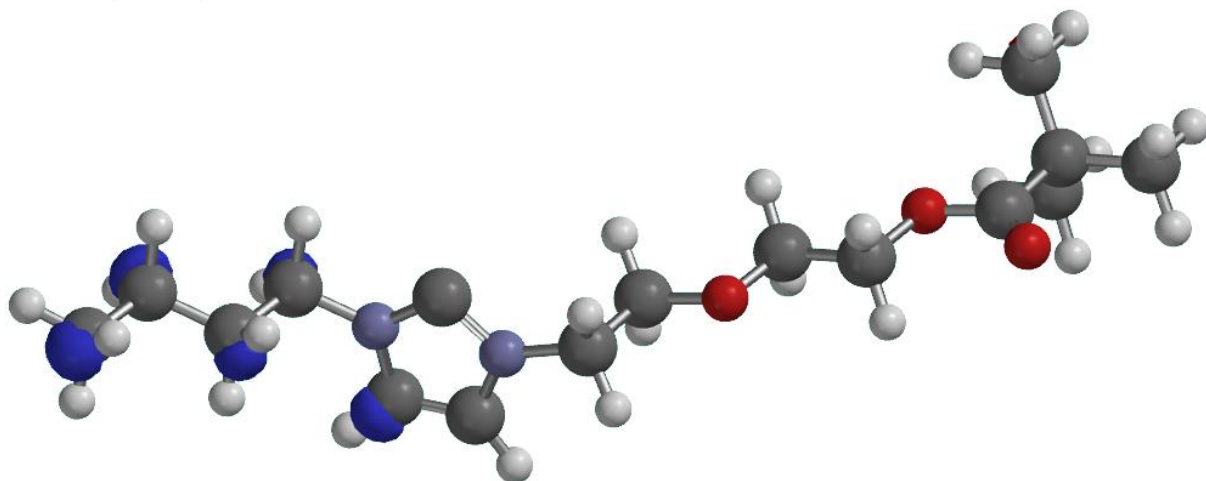
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C	1.1655167436	-2.0892737331	3.9930440886
C	1.7289710063	-1.6026124571	2.8618559234
N	1.0029089359	-0.4619124672	2.5294585280
C	-0.0142692338	-0.2092705506	3.4087637384
C	-0.7280529093	-1.3585385876	5.4909247603
C	-0.0527082014	-0.8260712942	6.7580803512
C	-0.9466372007	-0.9432523904	7.9965178808
C	-0.2808665185	-0.4103613134	9.2684877524
C	1.2428270055	0.3502773799	1.3442529689
C	0.5016465740	-0.1956212415	0.1264915220
O	0.8412506895	0.6208029430	-0.9818160683
C	0.1766234104	0.2561266193	-2.1772997104
C	0.6372607691	1.2198316833	-3.2561267388
O	-0.0467349896	0.8338593332	-4.4654914972

C	0.2595521775	1.5360793528	-5.5831674914
C	-0.5333018943	1.0428990307	-6.7994671706
O	1.0596064650	2.4392178571	-5.5830787020
C	-0.0742581422	1.8212864678	-8.0413745988
C	-0.2825099764	-0.4674252227	-6.9986460267
C	-2.0364033510	1.2924325080	-6.5443712050
H	1.4248488833	-2.9507485532	4.5863559656
H	2.5669422452	-1.9591604808	2.2857389662
H	-1.6396396804	-0.7972184460	5.2814178111
H	-1.0017007017	-2.4117670301	5.6141098996
H	0.2183361516	0.2218163117	6.5899132350
H	0.8852505287	-1.3686433263	6.9282910497
H	-1.8818693181	-0.3983864998	7.8196465506
H	-1.2291271098	-1.9926732473	8.1463504027
H	-0.9471002165	-0.4957907099	10.1312192952
H	0.6340240472	-0.9652514059	9.4990120032
H	-0.0100456643	0.6443195853	9.1606167230
H	2.3155830407	0.3830133470	1.1384412918
H	0.9022648808	1.3622112190	1.5599712063
H	0.7917826731	-1.2399251231	-0.0637928867
H	-0.5805242189	-0.1715816819	0.3123158259
H	0.4258218321	-0.7760373098	-2.4628847181
H	-0.9132119969	0.3197714779	-2.0518562356
H	1.7166557366	1.1598672964	-3.4053823578
H	0.3828206093	2.2498273558	-2.9988115015
H	0.9884377680	1.6638800403	-8.2377567014
H	-0.2319584887	2.8945049847	-7.9186802220
H	-0.6406241486	1.4852619330	-8.9143826406
H	0.7795555179	-0.6740228501	-7.1584368673
H	-0.8277707807	-0.8138467979	-7.8811379458
H	-0.6207038575	-1.0439723711	-6.1365006324
H	-2.3859550460	0.7472487797	-5.6659998039
H	-2.2408021527	2.3564351313	-6.3956997288
H	-2.6133706957	0.9566161250	-7.4106328191

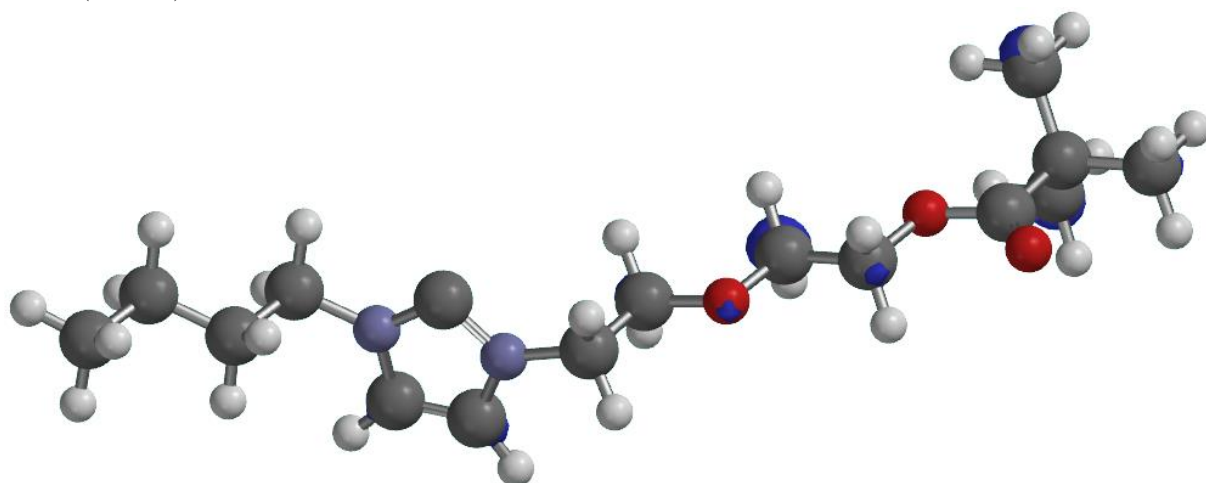
LUMO+2 (-0.10 eV)



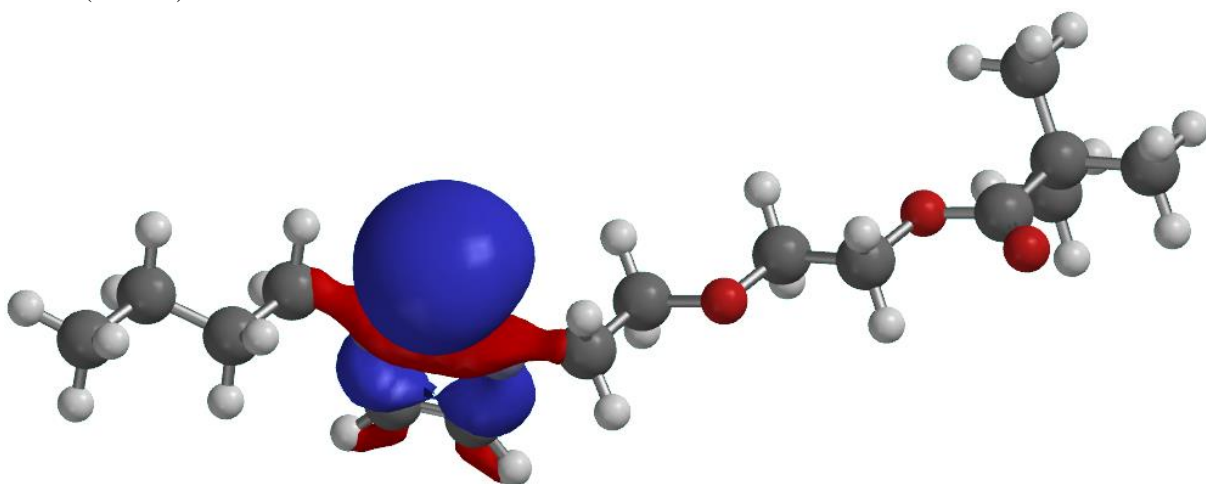
LUMO+1 (-0.28 eV)



LUMO (-0.35 eV)

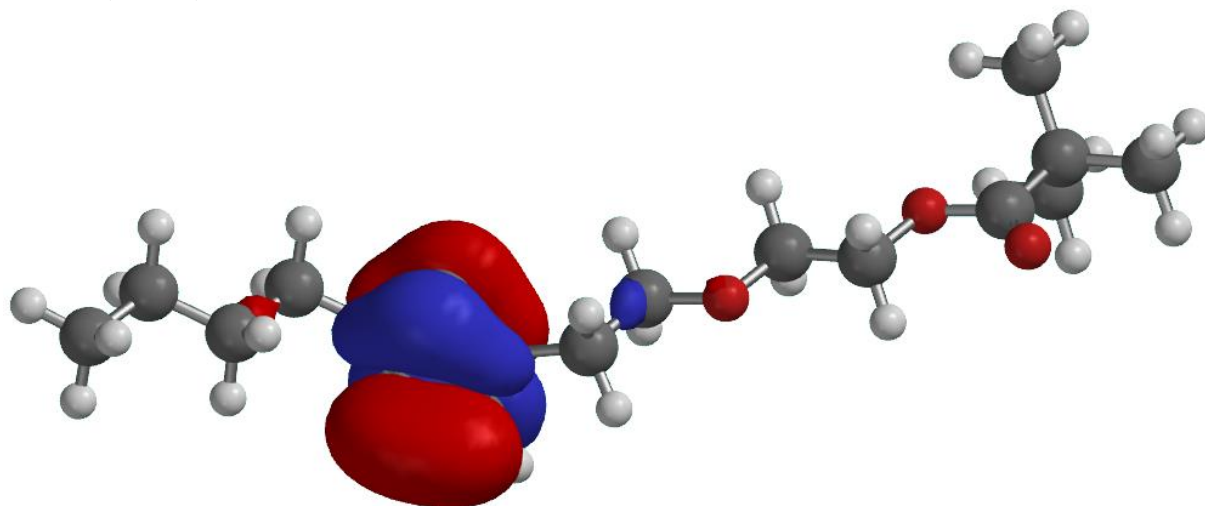


HOMO (-5.98 eV)

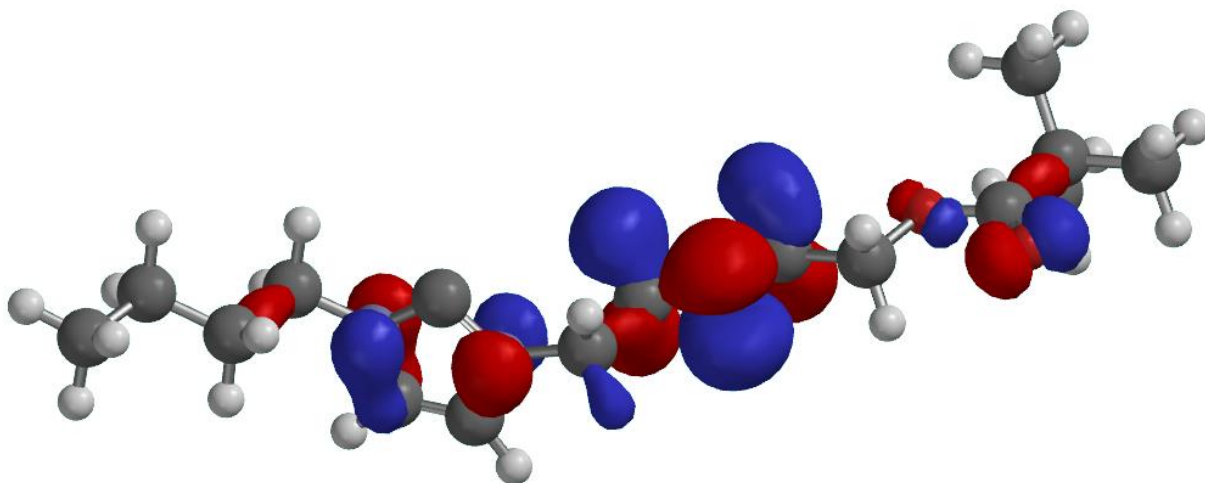




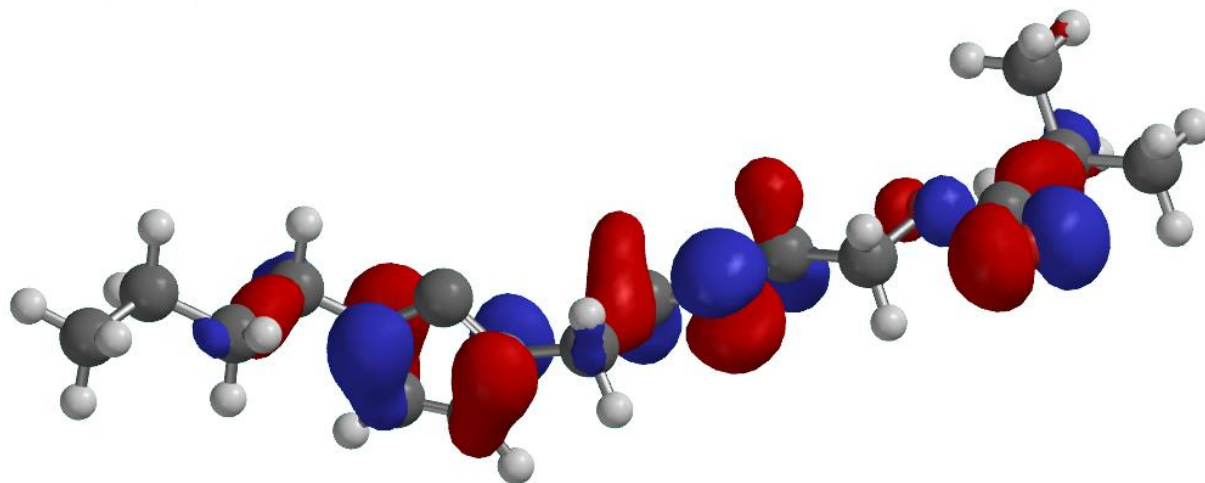
HOMO-1 (-6.42 eV)



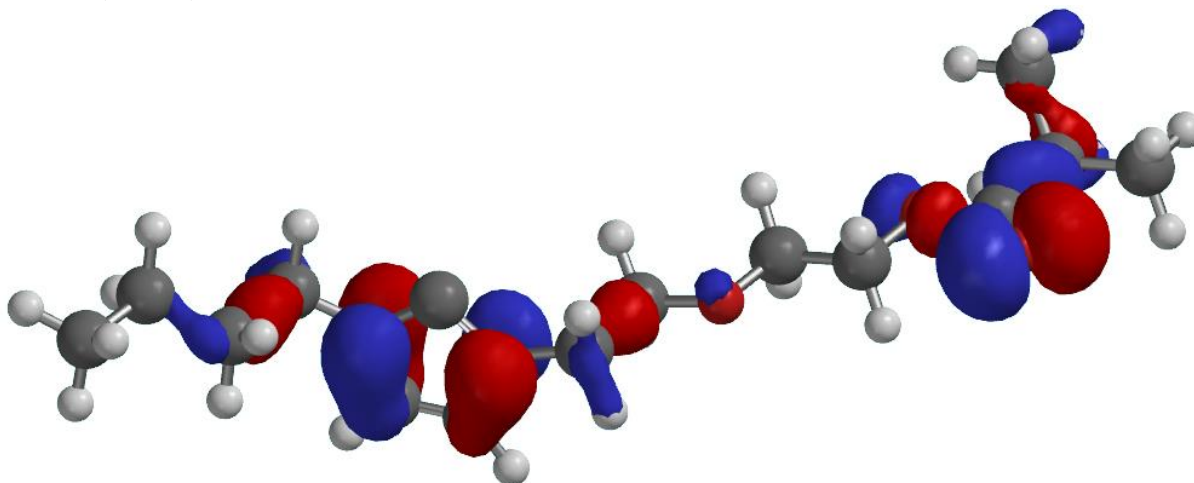
HOMO-2 (-7.55 eV)



HOMO-3 (-7.58 eV)



HOMO-4 (-7.62 eV)



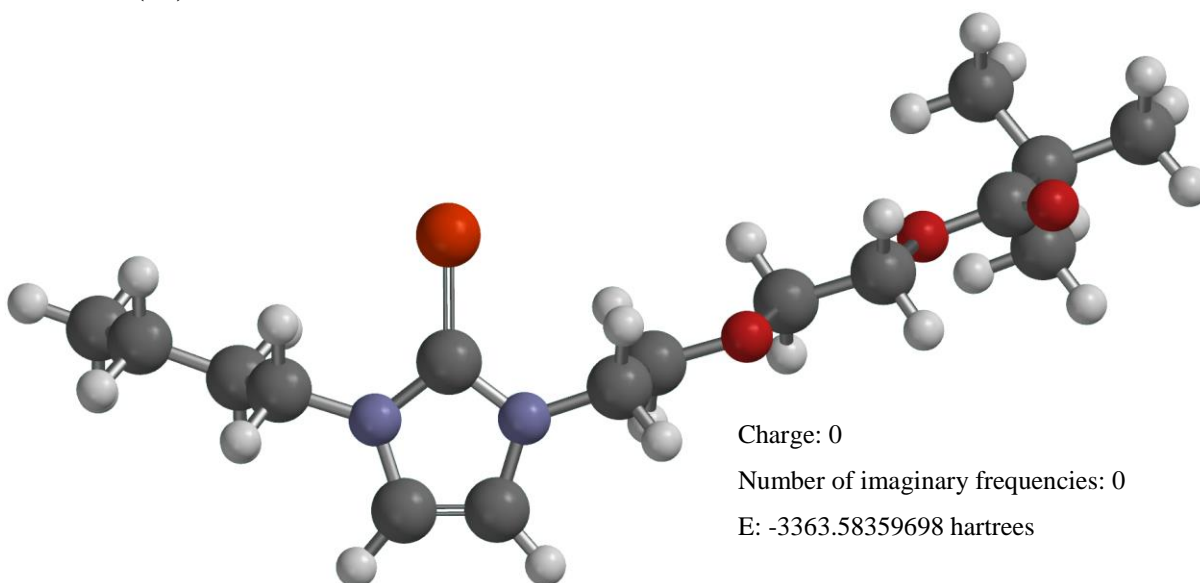
**Calculated CREF value for compound 1-butyl-3-(2-(2-(pivaloyloxy)ethoxy)ethyl)-1H-imidazol-3-ium and its carbene**

Cation:  
Electronic energy: -962.40819552 hartrees  
Zero point energy: 0.44173038 hartrees  
Sum of electronic energy and ZPE: -961.96646514 hartrees

Corresponding carbene:  
Electronic energy: -961.97805795 hartrees  
Zero point energy: 0.42800788 hartrees  
Sum of electronic energy and ZPE: -961.55005007 hartrees

Resulting CREF value: **0.416**

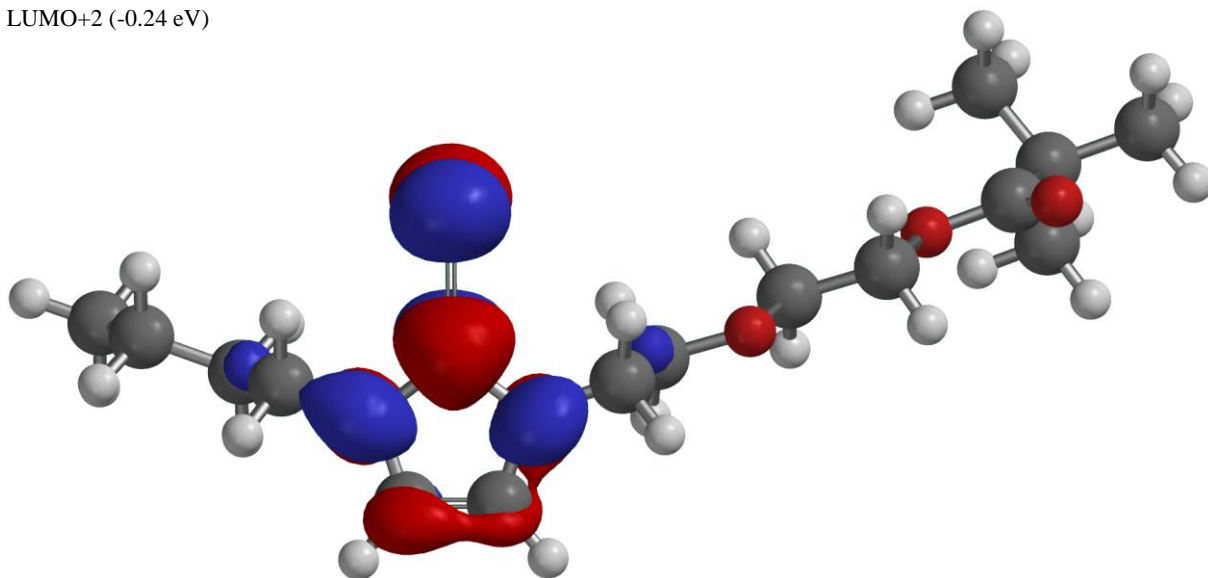
**Selenone (6a)**



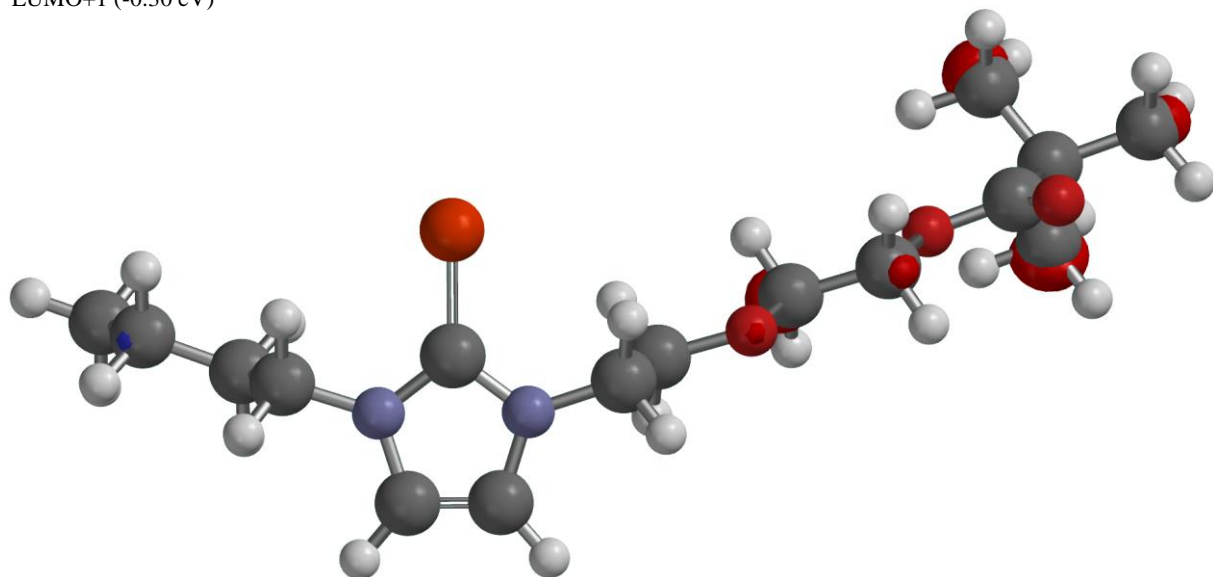
## Coordinates (Angstroem)

Atom	X	Y	Z
N	1.1113704467	0.0646596407	4.7135449023
C	2.4466729106	-0.2378079410	4.4927969156
C	2.7718342186	0.2395587253	3.2691935099
N	1.6318195411	0.8314025241	2.7427656808
C	0.5905661216	0.7243643803	3.6310827277
C	0.3525138513	-0.2954131657	5.9119707398
C	-0.2700391612	-1.6911633114	5.8238045947
C	-1.1155666990	-2.0249019784	7.0578655239
C	-1.7581242167	-3.4125736970	6.9785580389
Se	-1.1336380244	1.3448850507	3.4121503698
C	1.5507391637	1.4868256448	1.4421719636
C	1.0436227701	0.5418377845	0.3548832013
O	1.0524204460	1.2751389963	-0.8570417930
C	0.4489820997	0.5908099741	-1.9414616822
C	0.4793735856	1.5357869134	-3.1291443785
O	-0.1292614063	0.8313600210	-4.2304894112
C	-0.2318678944	1.5128529907	-5.3972594634
C	-0.8987585376	0.6706168447	-6.4913091596
O	0.1670150644	2.6443133861	-5.5247331032
C	-0.9914417864	1.5076014961	-7.7756428791
C	-0.0438885246	-0.5905909574	-6.7445250396
C	-2.3119883539	0.2598558680	-6.0240202727
H	3.0443319282	-0.7532634472	5.2245836208
H	3.7061496289	0.2228137703	2.7351456056
H	1.0332708053	-0.2192466674	6.7647370077
H	-0.4268323969	0.4605509055	6.0239432491
H	0.5204391118	-2.4414557942	5.7022765065
H	-0.8947942757	-1.7324111595	4.9261256860
H	-0.4918984681	-1.9622318430	7.9584656996
H	-1.8967967561	-1.2649845823	7.1703285486
H	-2.3453814916	-3.6302013947	7.8746150607
H	-2.4268903920	-3.4877907397	6.1159907190
H	-0.9992144682	-4.1951934497	6.8802123980
H	2.5453153248	1.8552704698	1.1839257195
H	0.8714650965	2.3352954175	1.5318356350
H	1.6952317455	-0.3417837538	0.2764991906
H	0.0290972966	0.2072490617	0.6038762609
H	0.9991582555	-0.3320269634	-2.1748997399
H	-0.5868032330	0.3185549521	-1.6979748998
H	1.5036637743	1.8123774558	-3.3863671734
H	-0.0798739761	2.4490613338	-2.9185150753
H	-0.0032362106	1.8161618064	-8.1222605930
H	-1.5831235821	2.4120468999	-7.6201880467
H	-1.4656487551	0.9162210056	-8.5638893819
H	0.9696601363	-0.3236695818	-7.0572983266
H	-0.4967551869	-1.1824921460	-7.5448858298
H	0.0239173724	-1.2133184048	-5.8510785416
H	-2.2721779991	-0.3465687592	-5.1177892372
H	-2.9345867616	1.1364915775	-5.8235630185
H	-2.8000421376	-0.3248751590	-6.8090120305

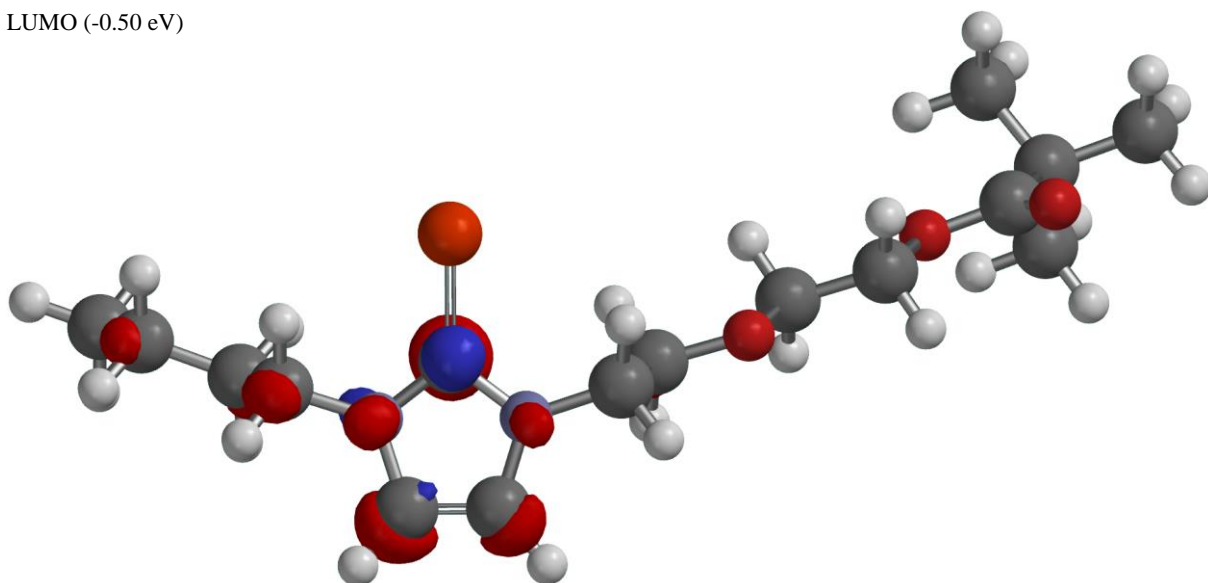
LUMO+2 (-0.24 eV)



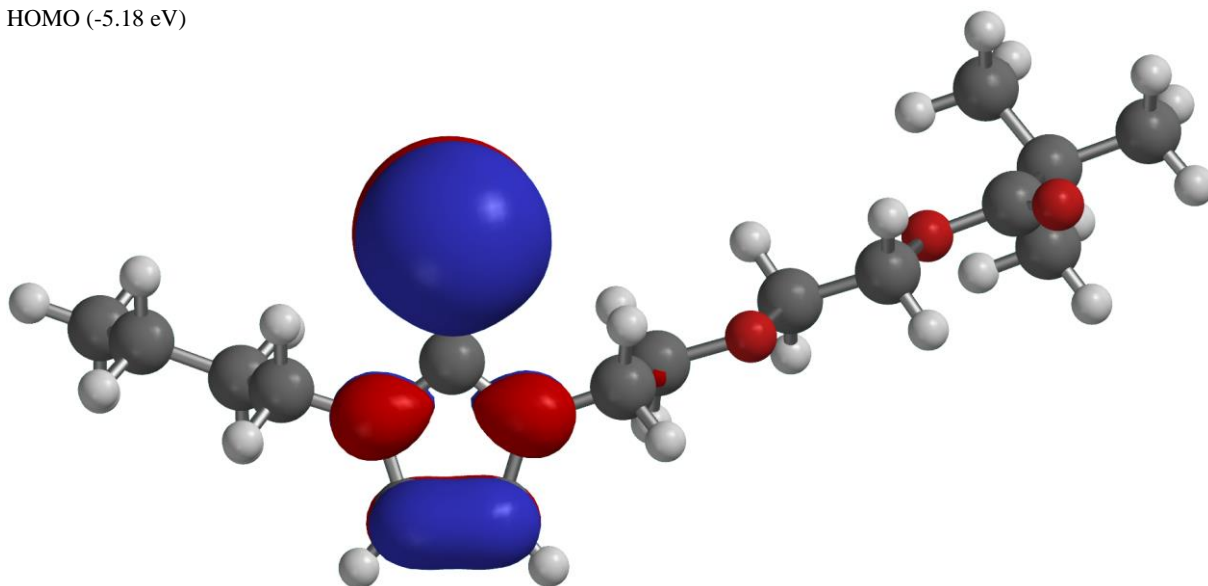
LUMO+1 (-0.30 eV)



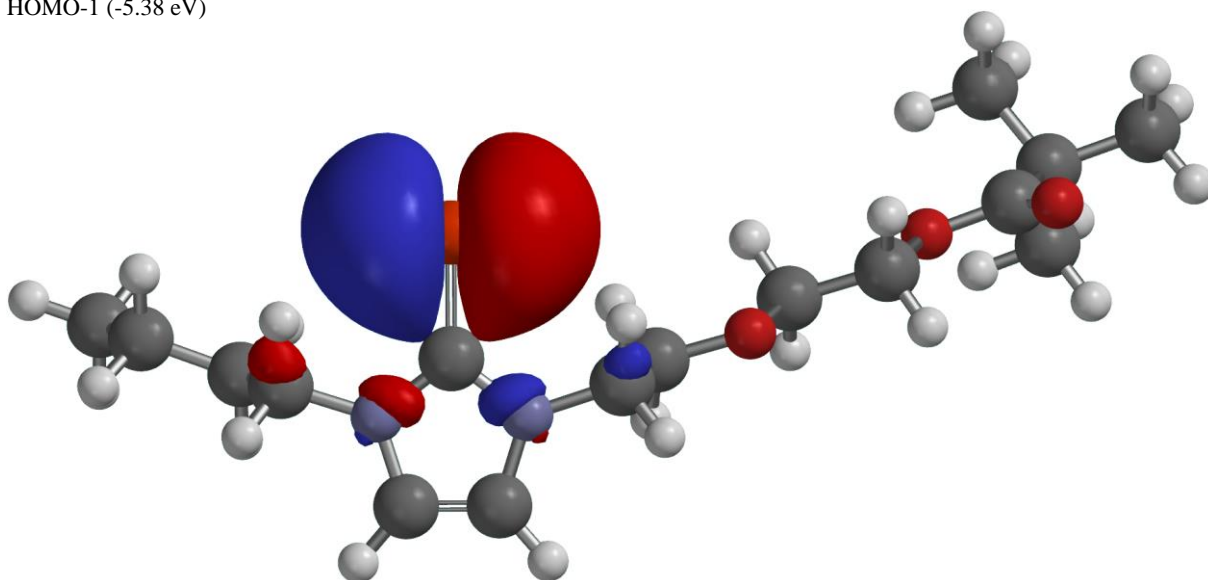
LUMO (-0.50 eV)



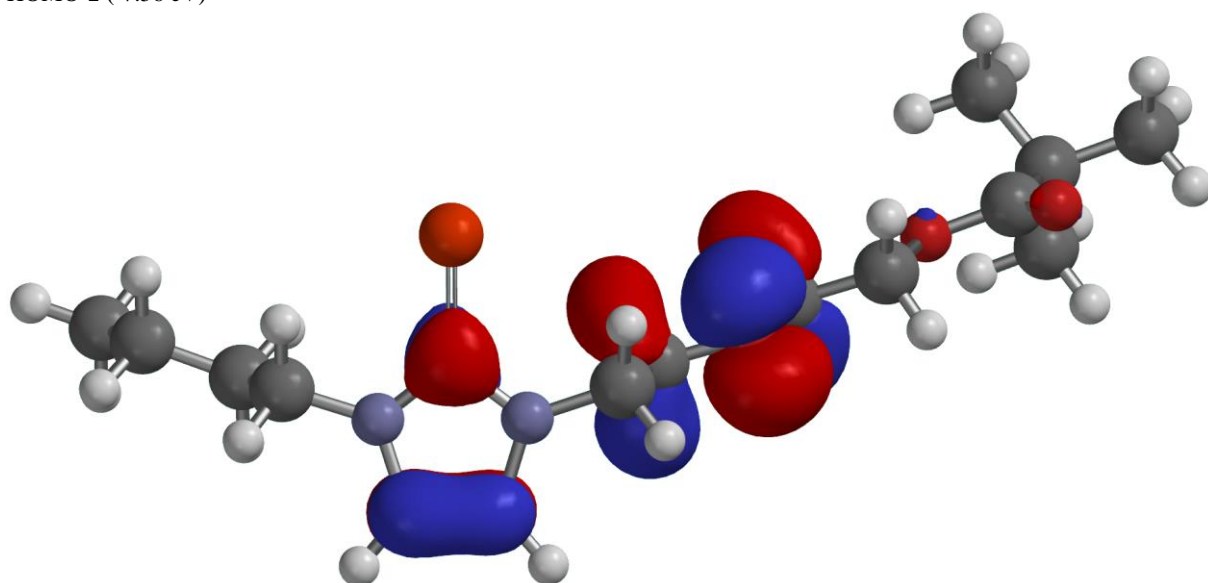
HOMO (-5.18 eV)



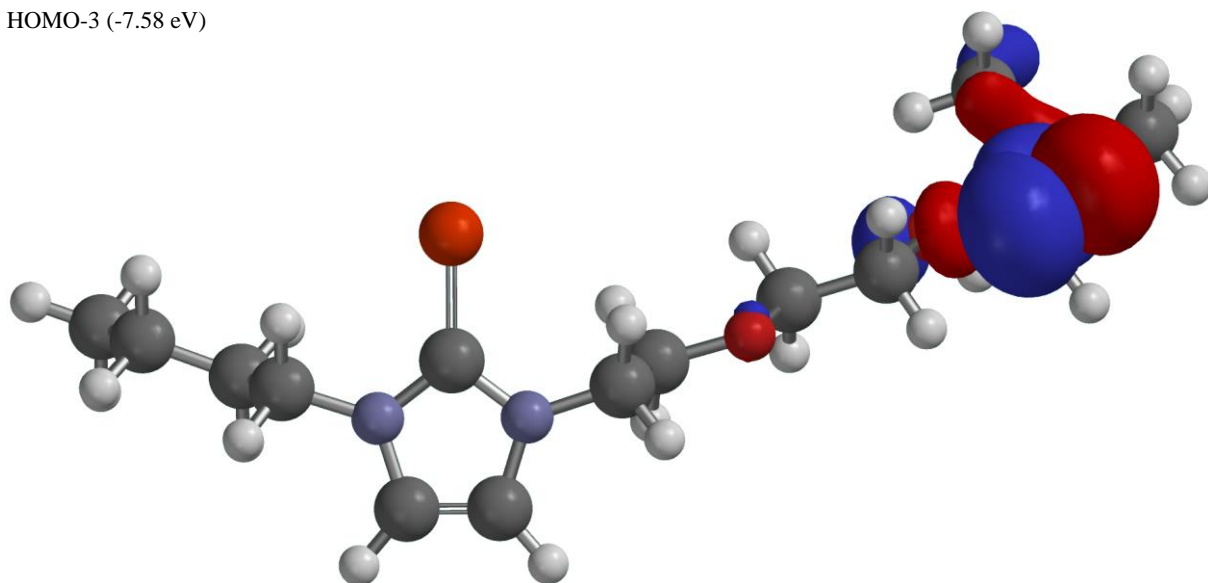
HOMO-1 (-5.38 eV)



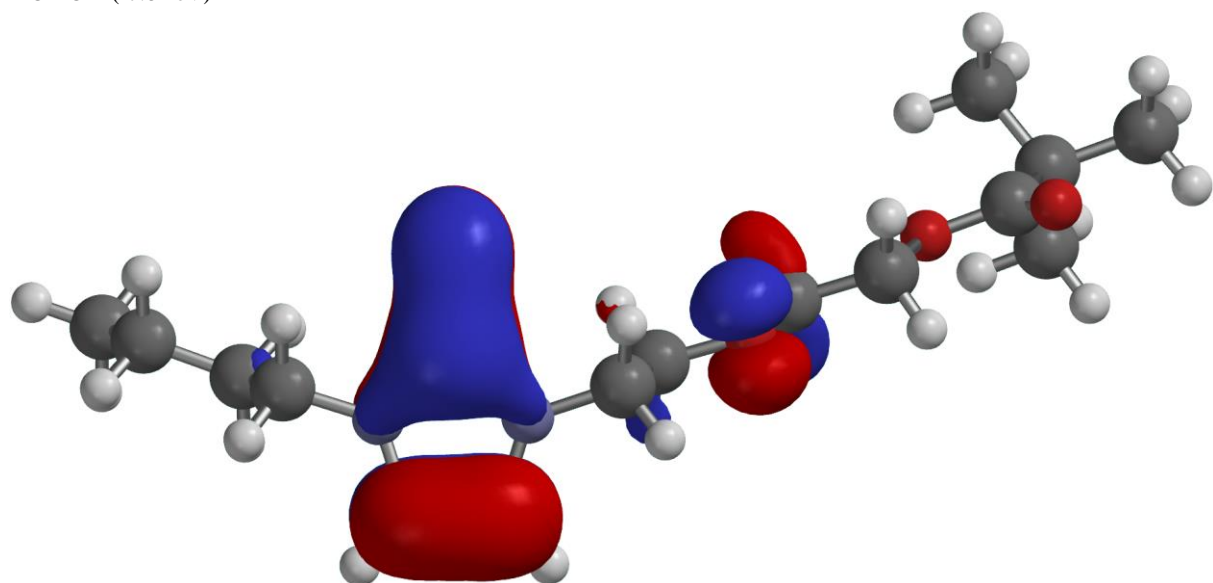
HOMO-2 (-7.56 eV)



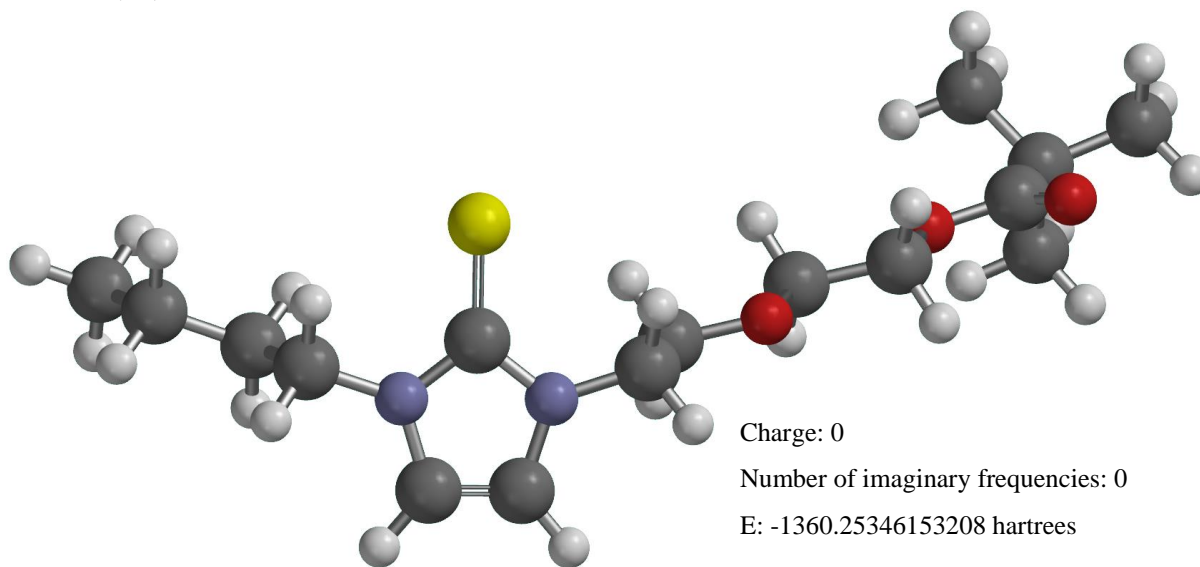
HOMO-3 (-7.58 eV)



HOMO-4 (-7.82 eV)



## Thione (5a)

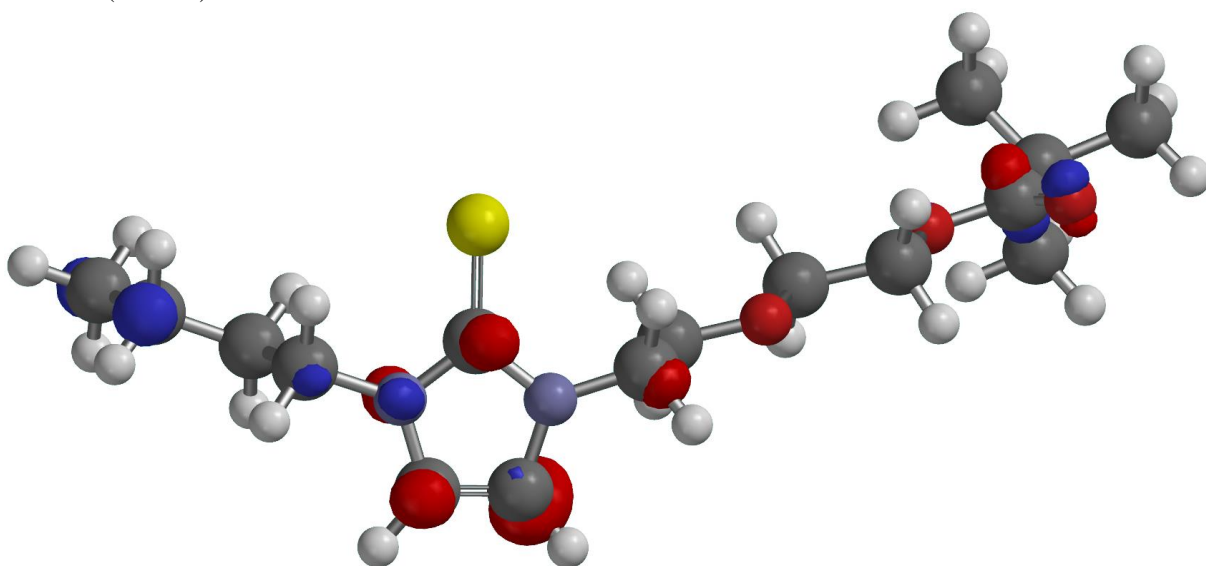


### Coordinates (Angstrom)

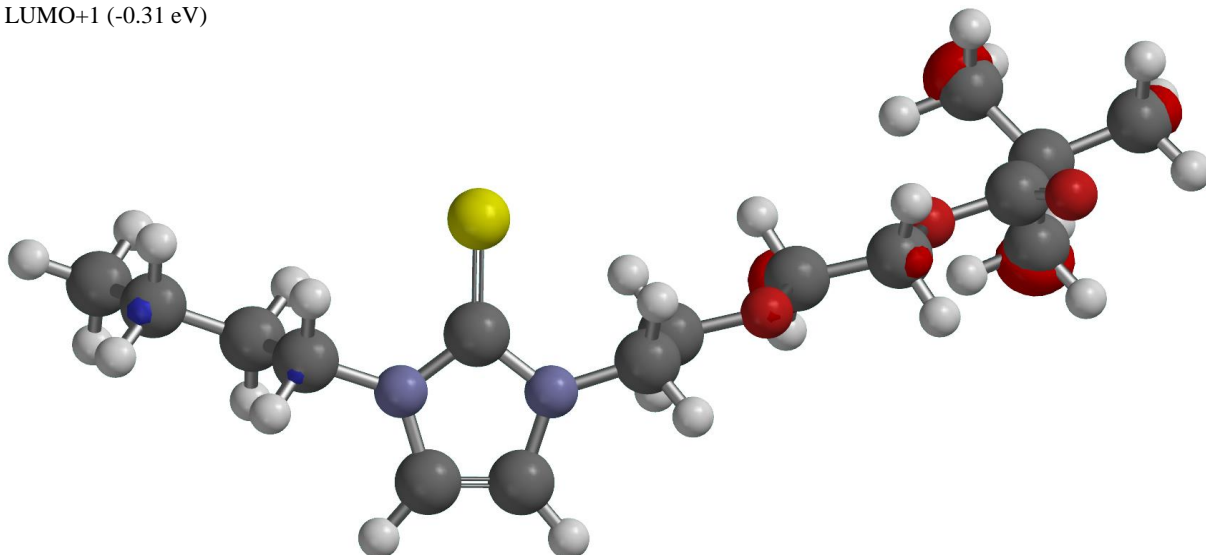
Atom	X	Y	Z
N	-2.0378249091	-0.0096922801	4.3872276440
C	-2.6976280829	1.1820454891	4.1249104308
C	-2.9185947972	1.2387283347	2.7917365688
N	-2.3915368303	0.0801435455	2.2361974137
C	-1.8325342202	-0.7076345776	3.2196759151
C	-1.6051809049	-0.4648279989	5.7066512539
C	-0.1951476237	0.0081076977	6.0720400851
C	0.2435543203	-0.4967194861	7.4505907443
C	1.6505460356	-0.0309604472	7.8355891334
C	-2.4291085313	-0.2699199867	0.8228517328
C	-1.1627554633	0.1720703467	0.0930625277
O	-1.3475450762	-0.1273429337	-1.2796306585
C	-0.1993994290	0.1251315772	-2.0700985522
C	-0.5370889733	-0.2780090487	-3.4942933137
O	0.6381926229	0.0007366438	-4.2816403056
C	0.5883980139	-0.3509895357	-5.5894918485
C	1.8813711722	0.0195882486	-6.3250622807
O	-0.3806771775	-0.8709988586	-6.0852952802
C	1.8115333188	-0.5258470726	-7.7590070408
C	2.0023681150	1.5598782128	-6.3520311175
C	3.0916750353	-0.5870064150	-5.5834018692
H	-2.9564486051	1.8752184575	4.9065579277
H	-3.4085250271	1.9872842073	2.1934281666
H	-2.3389725385	-0.1035435486	6.4329830551
H	-1.6472039046	-1.5554975888	5.6923025998
H	-0.1608194321	1.1041251316	6.0496302400
H	0.4993144956	-0.3505015967	5.3058426818
H	-0.4725902378	-0.1583161834	8.2099926523
H	0.2063667619	-1.5920107462	7.4607636772
H	1.9385622557	-0.4088890010	8.8202350497
H	2.3936674138	-0.3829558146	7.1138130384
H	1.7113462348	1.0613980875	7.8682348138
H	-3.3033535044	0.2057989084	0.3741255457
H	-2.5384558833	-1.3521079290	0.7461498646
H	-0.9970256186	1.2513630600	0.2314934186
H	-0.2976148854	-0.3675527434	0.4979267900
H	0.0723937525	1.1898640430	-2.0324706703

H	0.6573045623	-0.4580713719	-1.7060154308
H	-1.3847978812	0.2953493205	-3.8757341188
H	-0.7822409327	-1.3391121651	-3.5587418114
H	0.9525492286	-0.1187958222	-8.2955114513
H	1.7201981743	-1.6140763056	-7.7673699947
H	2.7207060820	-0.2519028504	-8.3016615691
H	1.1487128805	2.0148900488	-6.8625211774
H	2.9084432297	1.8451443193	-6.8939664297
H	2.0610750102	1.9707564264	-5.3426456890
H	3.1791497321	-0.1898457845	-4.5710420112
H	3.0110267457	-1.6760125987	-5.5206499096
H	4.0103456188	-0.3504159396	-6.1277126818
S	-1.0757303427	-2.1980654758	3.0319822410

LUMO+2 (-0.18 eV)

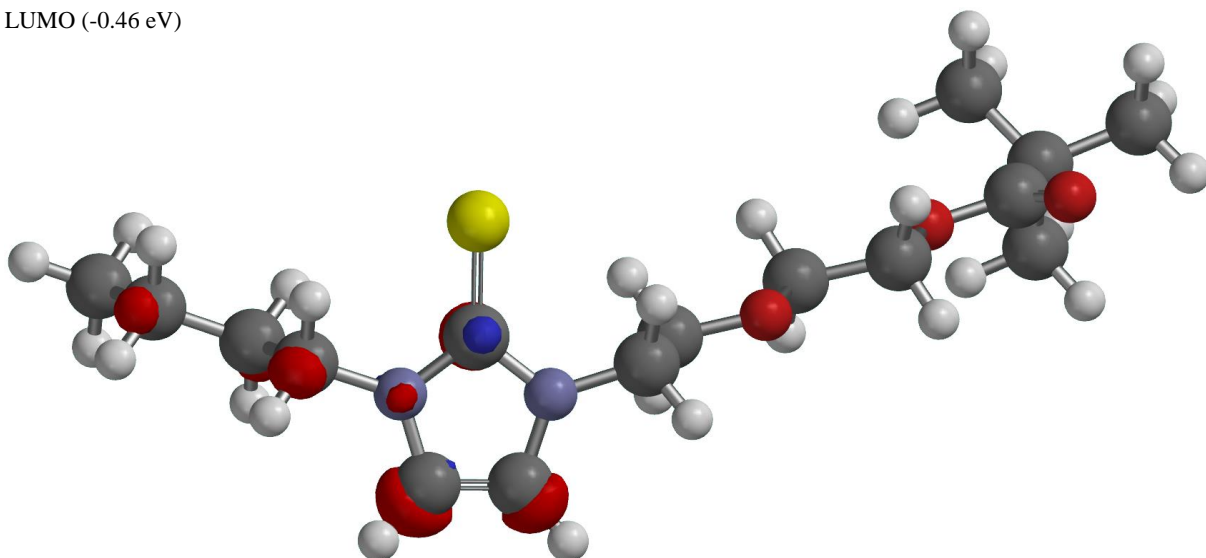


LUMO+1 (-0.31 eV)

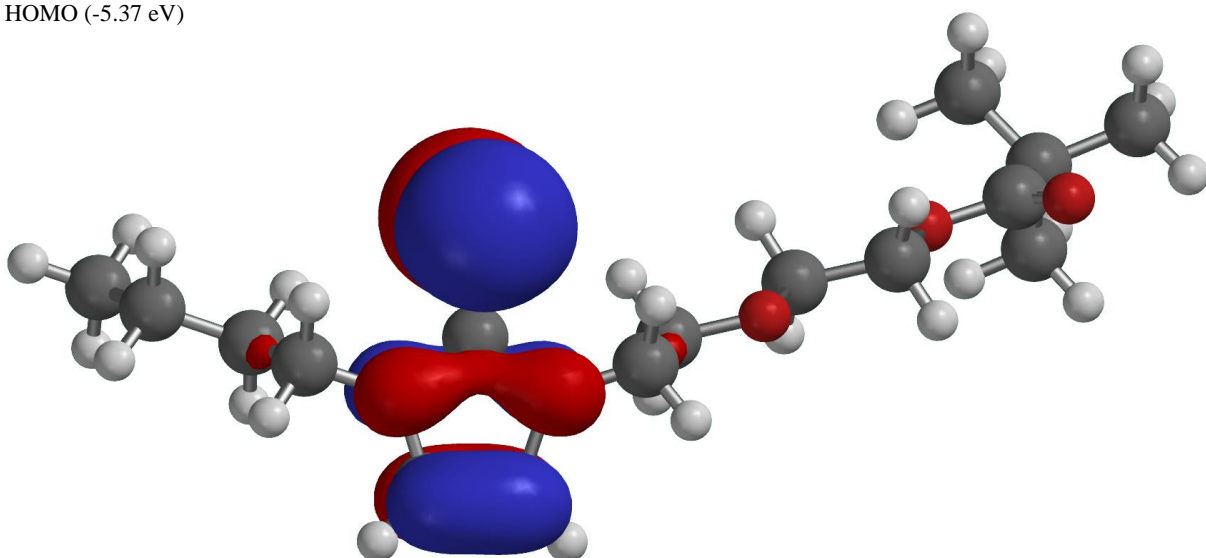




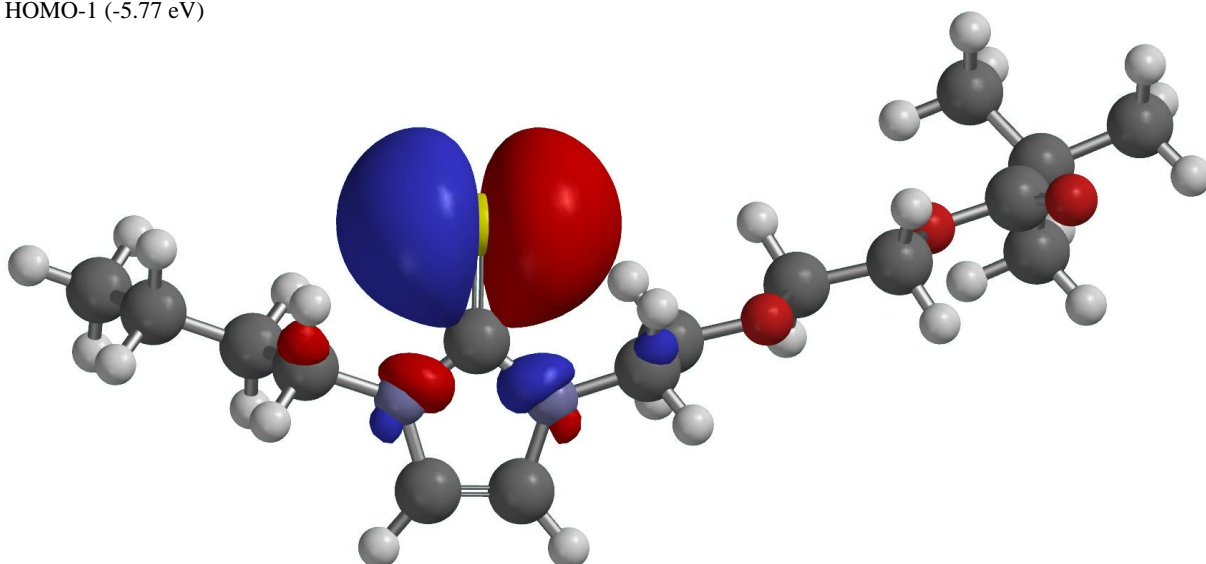
LUMO (-0.46 eV)



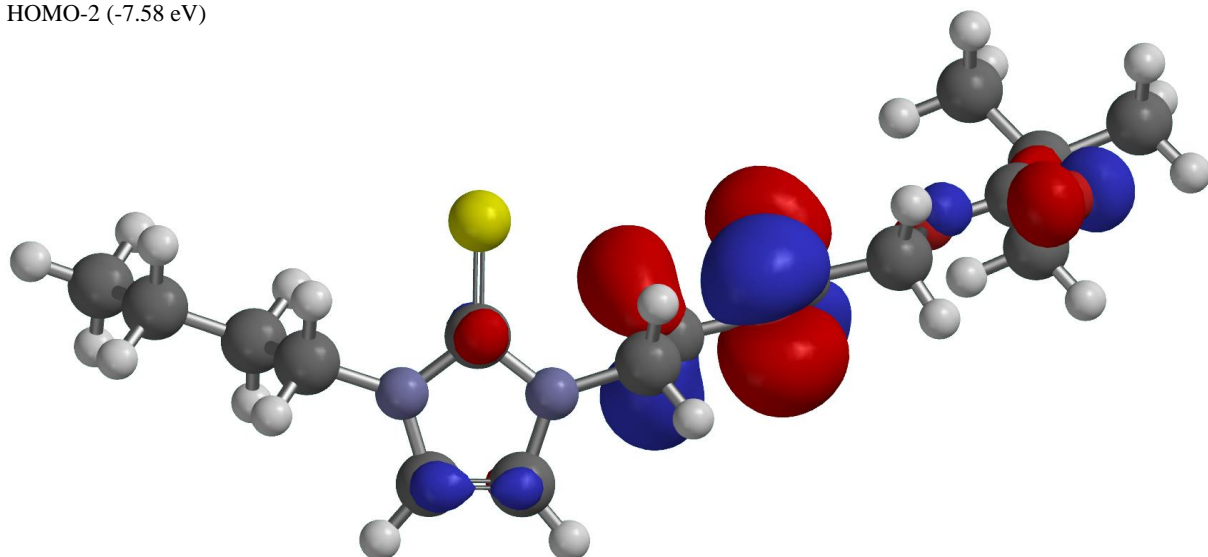
HOMO (-5.37 eV)



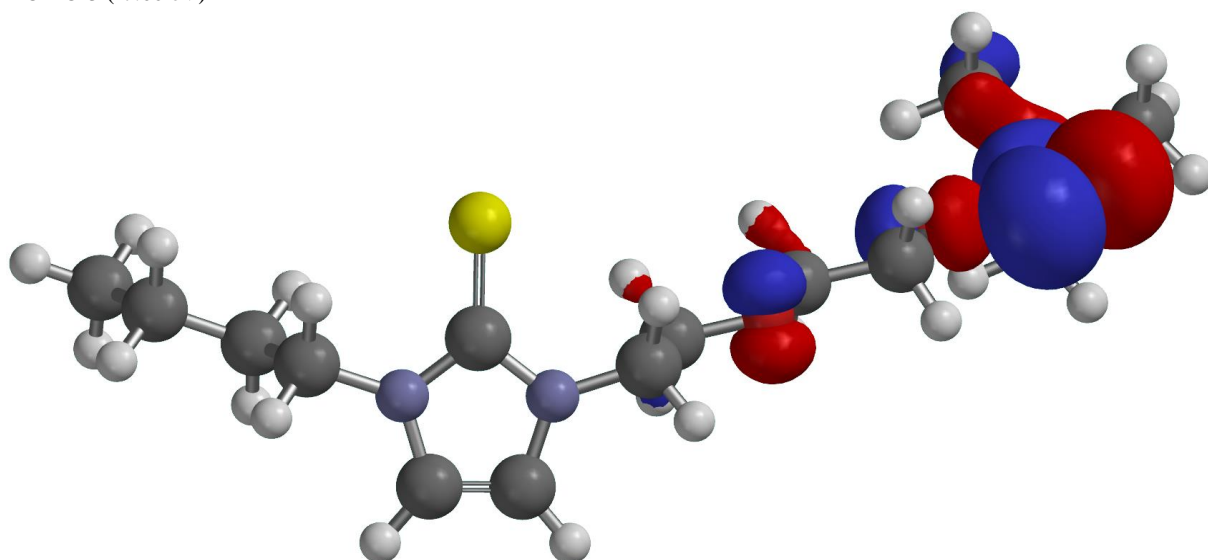
HOMO-1 (-5.77 eV)



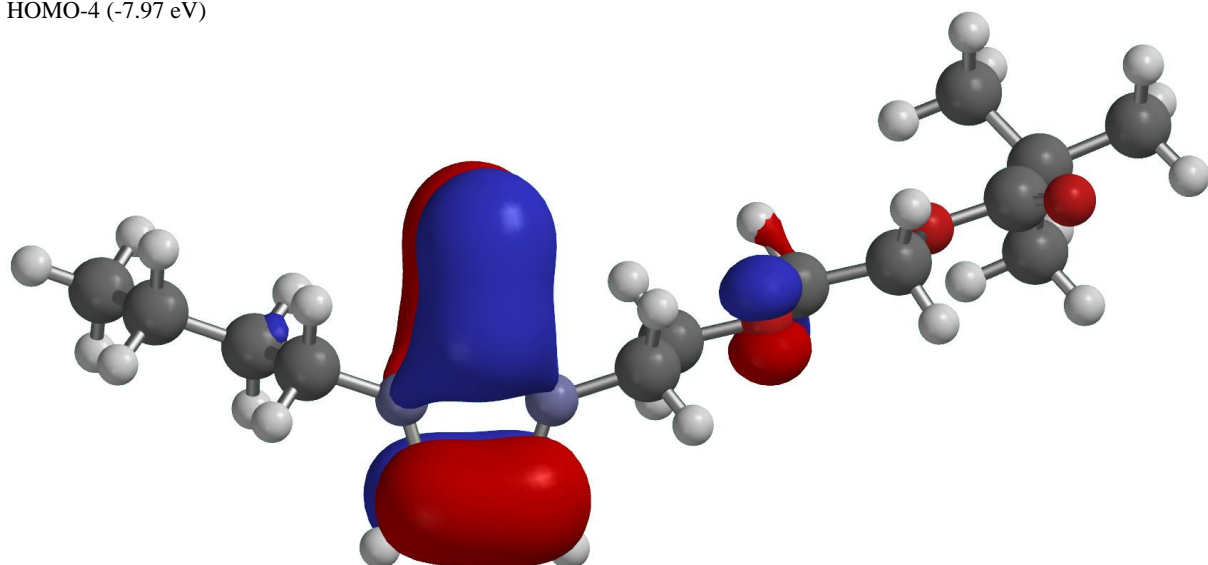
HOMO-2 (-7.58 eV)



HOMO-3 (-7.60 eV)



HOMO-4 (-7.97 eV)

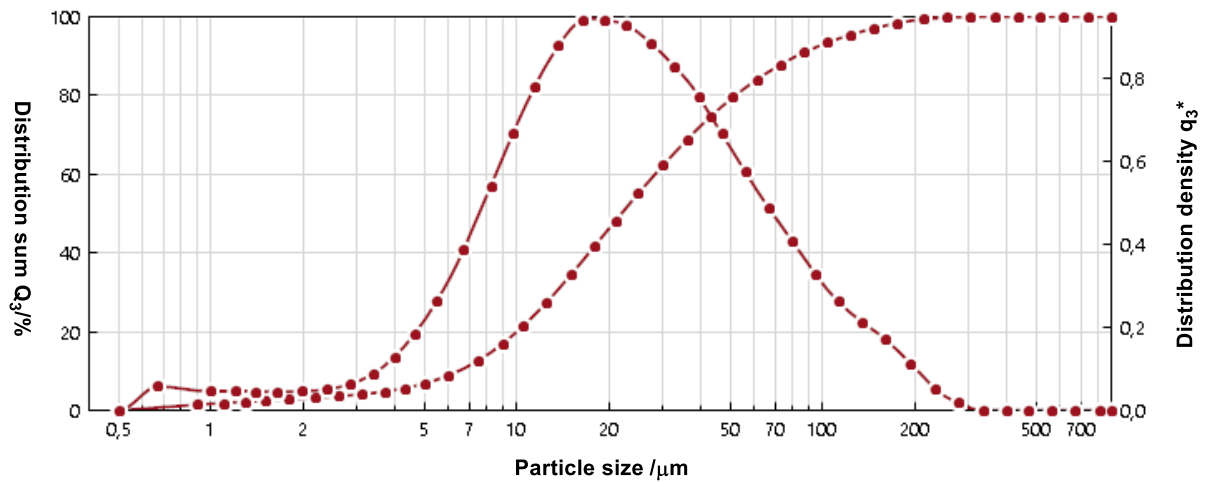


# 17. Particle size

## 17.1 Lithium aluminate

PAQXOS 4.3 **FREE**

$x_{10.3}$  = 6.41  $\mu\text{m}$        $x_{50.3}$  = 22.03  $\mu\text{m}$        $x_{90.3}$  = 82.25  $\mu\text{m}$       SMD = 10.62  $\mu\text{m}$        $C_{\text{opt}}$  = 8.82 %  
 $x_{16.3}$  = 8.64  $\mu\text{m}$        $x_{84.3}$  = 60.70  $\mu\text{m}$        $x_{99.3}$  = 196.31  $\mu\text{m}$       VMD = 35.55  $\mu\text{m}$       SY = 99.80%



Distribution sum

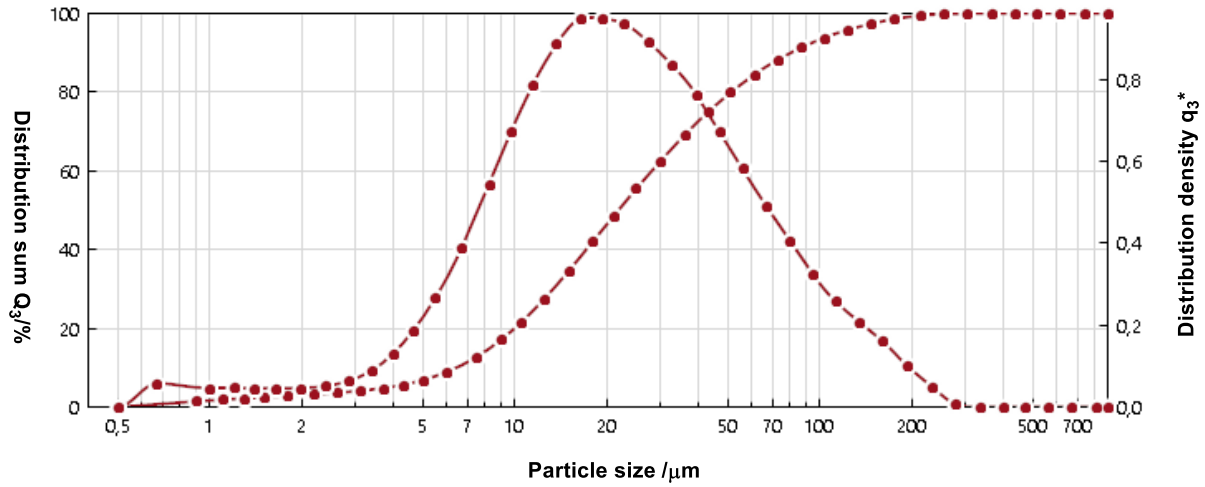
$x_0$ / $\mu\text{m}$	$Q_3$ / %	$x_0$ / $\mu\text{m}$	$Q_3$ / %
0.90	1.49	30.00	62.26
1.10	1.89	36.00	68.84
1.30	2.23	43.00	74.69
1.50	2.52	51.00	79.64
1.80	2.88	61.00	84.14
2.20	3.28	73.00	87.95
2.60	3.65	87.00	91.06
3.10	4.14	103.00	93.47
3.70	4.82	123.00	95.50
4.30	5.67	147.00	97.15
5.00	6.88	175.00	98.46
6.00	8.98	215.00	99.48
7.50	12.75	255.00	99.86
9.00	17.04	305.00	100.00
10.50	21.52	365.00	100.00
12.50	27.45	435.00	100.00
15.00	34.42	515.00	100.00
18.00	41.88	615.00	100.00
21.00	48.19	735.00	100.00
25.00	55.24	875.00	100.00

Distribution density (LOG.)

$x_m$ / $\mu\text{m}$	$q_3$ lg	$x_m$ / $\mu\text{m}$	$q_3$ lg
0.67	0.058	27.39	0.888
0.99	0.046	32.86	0.830
1.20	0.047	39.34	0.759
1.40	0.046	46.83	0.668
1.64	0.045	55.78	0.578
1.99	0.046	66.73	0.489
2.39	0.051	79.69	0.408
2.84	0.063	94.66	0.330
3.39	0.089	112.56	0.263
3.99	0.130	134.47	0.214
4.64	0.185	160.39	0.172
5.48	0.265	193.97	0.114
6.71	0.389	234.15	0.052
8.22	0.541	278.88	0.018
9.72	0.670	333.65	0.000
11.46	0.783	398.47	0.000
13.69	0.881	473.31	0.000
16.43	0.942	562.78	0.000
19.44	0.942	672.33	0.000
22.91	0.930	801.95	0.000

PAQXOS 4.3 FREE

$x_{10.3} = 6.39 \mu\text{m}$        $x_{50.3} = 21.89 \mu\text{m}$        $x_{90.3} = 80.30 \mu\text{m}$       SMD =  $10.57 \mu\text{m}$        $C_{\text{opt}} = 8.82 \%$   
 $x_{16.3} = 8.61 \mu\text{m}$        $x_{84.3} = 59.76 \mu\text{m}$        $x_{99.3} = 188.57 \mu\text{m}$       VMD =  $34.84 \mu\text{m}$       SY =  $99.81 \%$



Distribution sum

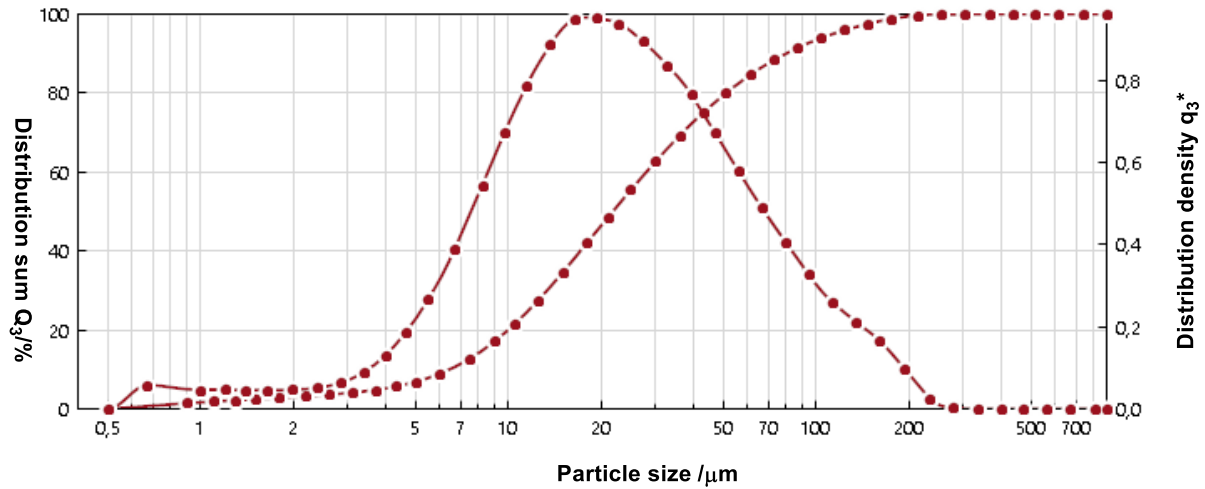
$x_0 / \mu\text{m}$	$Q_3 / \%$	$x_0 / \mu\text{m}$	$Q_3 / \%$
0.90	1.50	30.00	62.57
1.10	1.90	36.00	69.18
1.30	2.24	43.00	75.06
1.50	2.53	51.00	80.04
1.80	2.89	61.00	84.56
2.20	3.30	73.00	88.38
2.60	3.67	87.00	91.48
3.10	4.16	103.00	93.87
3.70	4.84	123.00	95.86
4.30	5.70	147.00	97.47
5.00	6.92	175.00	98.70
6.00	9.02	215.00	99.59
7.50	12.81	255.00	99.95
9.00	17.11	305.00	100.00
10.50	21.62	365.00	100.00
12.50	27.57	435.00	100.00
15.00	34.58	515.00	100.00
18.00	42.09	615.00	100.00
21.00	48.43	735.00	100.00
25.00	55.51	875.00	100.00

Distribution density (LOG.)

$x_m / \mu\text{m}$	$q_3 \lg$	$x_m / \mu\text{m}$	$q_3 \lg$
0.67	0.059	27.39	0.892
0.99	0.046	32.86	0.834
1.20	0.047	39.34	0.762
1.40	0.046	46.83	0.672
1.64	0.046	55.78	0.581
1.99	0.047	66.73	0.491
2.39	0.051	79.69	0.407
2.84	0.064	94.66	0.326
3.39	0.089	112.56	0.258
3.99	0.131	134.47	0.208
4.64	0.186	160.39	0.162
5.48	0.266	193.97	0.100
6.71	0.391	234.15	0.049
8.22	0.544	278.88	0.006
9.72	0.673	333.65	0.000
11.46	0.787	398.47	0.000
13.69	0.886	473.31	0.000
16.43	0.948	562.78	0.000
19.44	0.948	672.33	0.000
22.91	0.935	801.95	0.000

PAQXOS 4.3 FREE

$x_{10.3} = 6.39 \mu\text{m}$        $x_{50.3} = 21.85 \mu\text{m}$        $x_{90.3} = 79.80 \mu\text{m}$       SMD =  $10.57 \mu\text{m}$        $C_{\text{opt}} = 8.81 \%$   
 $x_{16.3} = 8.61 \mu\text{m}$        $x_{84.3} = 59.48 \mu\text{m}$        $x_{99.3} = 179.28 \mu\text{m}$       VMD =  $34.50 \mu\text{m}$       SY =  $99.81 \%$



Distribution sum

$x_0 / \mu\text{m}$	$Q_3 / \%$	$x_0 / \mu\text{m}$	$Q_3 / \%$
0.90	1.49	30.00	62.67
1.10	1.90	36.00	69.29
1.30	2.24	43.00	75.19
1.50	2.53	51.00	80.17
1.80	2.89	61.00	84.69
2.20	3.30	73.00	88.50
2.60	3.67	87.00	91.59
3.10	4.16	103.00	93.99
3.70	4.84	123.00	96.00
4.30	5.70	147.00	97.64
5.00	6.92	175.00	98.91
6.00	9.03	215.00	99.78
7.50	12.82	255.00	99.97
9.00	17.12	305.00	100.00
10.50	21.63	365.00	100.00
12.50	27.59	435.00	100.00
15.00	34.61	515.00	100.00
18.00	42.13	615.00	100.00
21.00	48.49	735.00	100.00
25.00	55.59	875.00	100.00

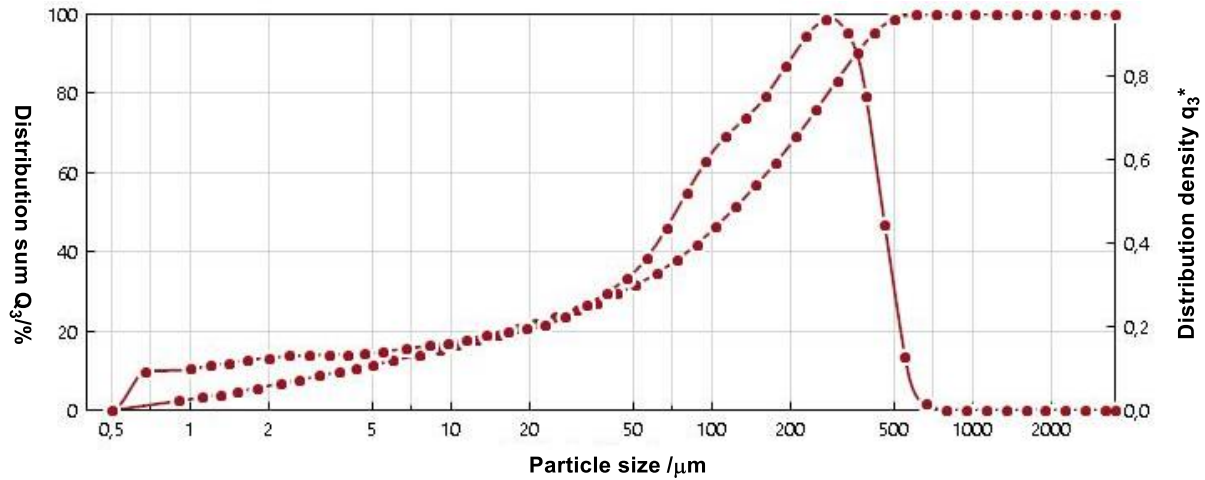
Distribution density (LOG.)

$x_m / \mu\text{m}$	$q_3 \lg$	$x_m / \mu\text{m}$	$q_3 \lg$
0.67	0.059	27.39	0.894
0.99	0.046	32.86	0.836
1.20	0.047	39.34	0.764
1.40	0.046	46.83	0.673
1.64	0.046	55.78	0.580
1.99	0.047	66.73	0.489
2.39	0.052	79.69	0.406
2.84	0.064	94.66	0.327
3.39	0.089	112.56	0.261
3.99	0.131	134.47	0.212
4.64	0.186	160.39	0.167
5.48	0.266	193.97	0.098
6.71	0.391	234.15	0.026
8.22	0.544	278.88	0.003
9.72	0.673	333.65	0.000
11.46	0.787	398.47	0.000
13.69	0.887	473.31	0.000
16.43	0.949	562.78	0.000
19.44	0.950	672.33	0.000
22.91	0.938	801.95	0.000

## 17.2 Gehlenite

PAQXOS 4.3 **FREE**

$x_{10,3} = 3.88 \mu\text{m}$        $x_{50,3} = 117.59 \mu\text{m}$        $x_{90,3} = 356.05 \mu\text{m}$       SMD =  $10.23 \mu\text{m}$        $C_{\text{opt}} = 11.20\%$   
 $x_{16,3} = 10.00 \mu\text{m}$        $x_{84,3} = 305.88 \mu\text{m}$        $x_{99,3} = 512.38 \mu\text{m}$       VMD =  $152.20 \mu\text{m}$       SY =  $99.72\%$



Distribution sum

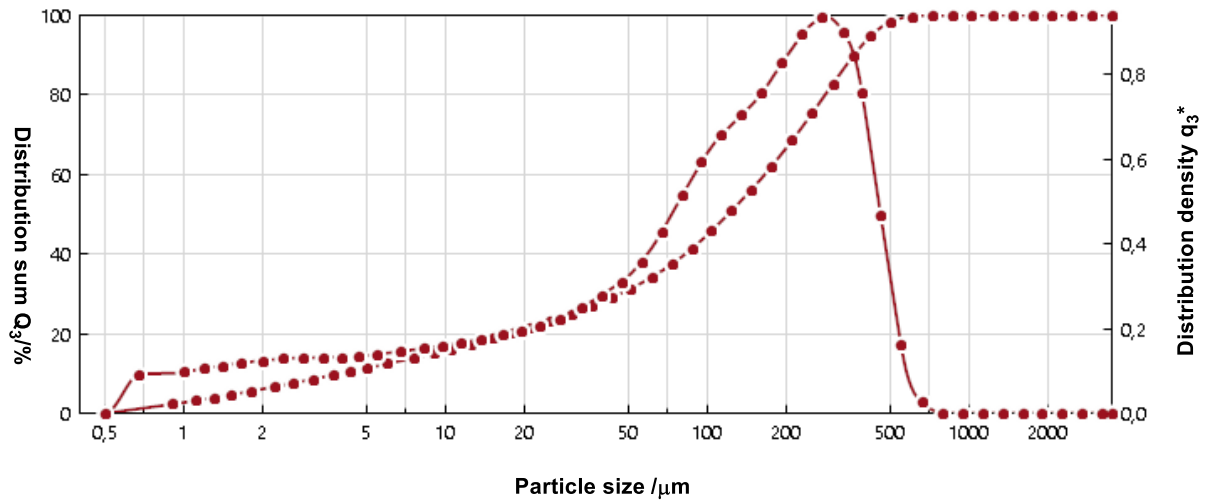
$x_0 / \mu\text{m}$	$Q_3 / \%$	$x_0 / \mu\text{m}$	$Q_3 / \%$
0.90	2.36	61.00	34.52
1.10	3.22	73.00	37.93
1.30	4.00	87.00	41.91
1.50	4.71	103.00	46.30
1.80	5.66	123.00	51.37
2.20	6.76	147.00	56.81
2.60	7.71	175.00	62.52
3.10	8.72	210.00	69.06
3.70	9.74	250.00	75.86
4.30	10.62	300.00	83.30
5.00	11.50	360.00	90.47
6.00	12.62	420.00	95.51
7.50	14.05	500.00	98.87
9.00	15.28	600.00	99.89
10.50	16.36	720.00	100.00
12.50	17.64	860.00	100.00
15.00	19.05	1020.00	100.00
18.00	20.55	1220.00	100.00
21.00	21.87	1460.00	100.00
25.00	23.43	1740.00	100.00
30.00	25.20	2060.00	100.00
36.00	27.18	2460.00	100.00
43.00	29.36	2940.00	100.00
51.00	31.69	3500.00	100.00

Distribution density (LOG.)

$x_m / \mu\text{m}$	$q_3 \lg$	$x_m / \mu\text{m}$	$q_3 \lg$
0.67	0.093	55.78	0.365
0.99	0.098	66.73	0.437
1.20	0.108	79.69	0.522
1.40	0.114	94.66	0.599
1.64	0.120	112.56	0.657
1.99	0.126	134.47	0.702
2.39	0.130	160.39	0.754
2.84	0.132	191.70	0.827
3.39	0.133	229.13	0.898
3.99	0.134	273.86	0.939
4.64	0.136	328.63	0.906
5.48	0.141	388.84	0.753
6.71	0.148	458.26	0.444
8.22	0.155	547.72	0.128
9.72	0.162	657.27	0.014
11.46	0.168	786.89	0.000
13.69	0.179	936.59	0.000
16.43	0.189	1115.53	0.000
19.44	0.197	1334.62	0.000
22.91	0.206	1593.86	0.000
27.39	0.224	1893.25	0.000
32.86	0.251	2251.13	0.000
39.34	0.282	2689.31	0.000
46.83	0.315	3207.80	0.000

PAQXOS 4.3 **FREE**

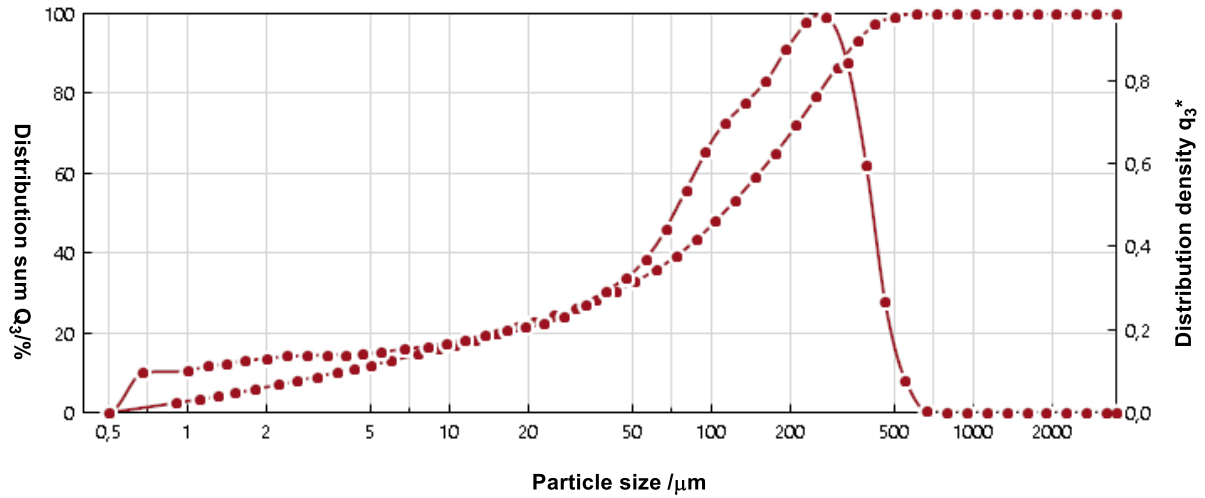
$x_{10,3}$  = 3.94  $\mu\text{m}$        $x_{50,3}$  = 119.61  $\mu\text{m}$        $x_{90,3}$  = 360.99  $\mu\text{m}$       SMD = 10.33  $\mu\text{m}$        $C_{\text{opt}}$  = 11.22%  
 $x_{16,3}$  = 10.20  $\mu\text{m}$        $x_{84,3}$  = 310.30  $\mu\text{m}$        $x_{99,3}$  = 538.11  $\mu\text{m}$       VMD = 154.80  $\mu\text{m}$       SY = 99.73%



Distribution sum				Distribution density (LOG.)			
$x_0$ / $\mu\text{m}$	$Q_3$ / %	$x_0$ / $\mu\text{m}$	$Q_3$ / %	$x_m$ / $\mu\text{m}$	$q_3$ lg	$x_m$ / $\mu\text{m}$	$q_3$ lg
0.90	2.34	61.00	34.18	0.67	0.092	55.78	0.359
1.10	3.19	73.00	37.52	0.99	0.097	66.73	0.429
1.30	3.96	87.00	41.44	1.20	0.107	79.69	0.514
1.50	4.66	103.00	45.79	1.40	0.113	94.66	0.594
1.80	5.61	123.00	50.86	1.64	0.119	112.56	0.658
2.20	6.70	147.00	56.31	1.99	0.125	134.47	0.705
2.60	7.63	175.00	62.04	2.39	0.129	160.39	0.756
3.10	8.64	210.00	68.59	2.84	0.131	191.70	0.827
3.70	9.65	250.00	75.37	3.39	0.132	229.13	0.896
4.30	10.52	300.00	82.77	3.99	0.133	273.86	0.935
5.00	11.40	360.00	89.92	4.64	0.135	328.63	0.902
6.00	12.51	420.00	94.98	5.48	0.140	388.84	0.756
7.50	13.93	500.00	98.51	6.71	0.147	458.26	0.467
9.00	15.14	600.00	99.79	8.22	0.153	547.72	0.161
10.50	16.22	720.00	100.00	9.72	0.160	657.27	0.026
12.50	17.48	860.00	100.00	11.46	0.166	786.89	0.000
15.00	18.87	1020.00	100.00	13.69	0.176	936.59	0.000
18.00	20.33	1220.00	100.00	16.43	0.185	1115.53	0.000
21.00	21.63	1460.00	100.00	19.44	0.193	1334.62	0.000
25.00	23.18	1740.00	100.00	22.91	0.205	1593.86	0.000
30.00	24.95	2060.00	100.00	27.39	0.224	1893.25	0.000
36.00	26.93	2460.00	100.00	32.86	0.250	2251.13	0.000
43.00	29.08	2940.00	100.00	39.34	0.279	2689.31	0.000
51.00	31.39	3500.00	100.00	46.83	0.311	3207.80	0.000

PAQXOS 4.3 FREE

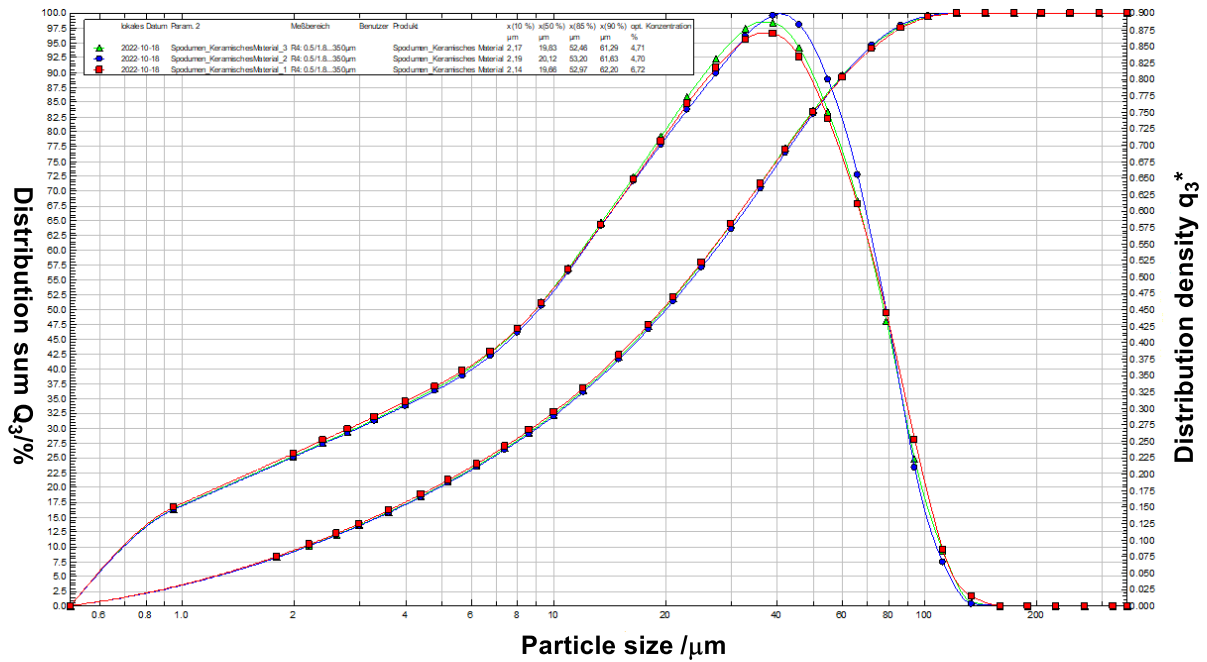
$x_{10,3} = 3.64 \mu\text{m}$        $x_{50,3} = 110.78 \mu\text{m}$        $x_{90,3} = 330.06 \mu\text{m}$       SMD =  $9.88 \mu\text{m}$        $C_{\text{opt}} = 11.22\%$   
 $x_{16,3} = 9.21 \mu\text{m}$        $x_{84,3} = 282.36 \mu\text{m}$        $x_{99,3} = 486.48 \mu\text{m}$       VMD =  $141.18 \mu\text{m}$       SY =  $99.67\%$



Distribution sum				Distribution density (LOG.)			
$x_0 / \mu\text{m}$	$Q_3 / \%$	$x_0 / \mu\text{m}$	$Q_3 / \%$	$x_m / \mu\text{m}$	$q_3 \lg$	$x_m / \mu\text{m}$	$q_3 \lg$
0.90	2.44	61.00	35.77	0.67	0.096	55.78	0.370
1.10	3.33	73.00	39.22	0.99	0.102	66.73	0.443
1.30	4.14	87.00	43.31	1.20	0.112	79.69	0.536
1.50	4.87	103.00	47.91	1.40	0.118	94.66	0.627
1.80	5.86	123.00	53.29	1.64	0.125	112.56	0.698
2.20	7.00	147.00	59.06	1.99	0.131	134.47	0.746
2.60	7.99	175.00	65.09	2.39	0.136	160.39	0.797
3.10	9.04	210.00	72.01	2.84	0.138	191.70	0.873
3.70	10.10	250.00	79.12	3.39	0.139	229.13	0.940
4.30	11.01	300.00	86.66	3.99	0.139	273.86	0.952
5.00	11.94	360.00	93.33	4.64	0.141	328.63	0.843
6.00	13.09	420.00	97.31	5.48	0.146	388.84	0.595
7.50	14.58	500.00	99.34	6.71	0.153	458.26	0.268
9.00	15.84	600.00	99.97	8.22	0.160	547.72	0.079
10.50	16.96	720.00	100.00	9.72	0.168	657.27	0.004
12.50	18.29	860.00	100.00	11.46	0.175	786.89	0.000
15.00	19.76	1020.00	100.00	13.69	0.186	936.59	0.000
18.00	21.33	1220.00	100.00	16.43	0.198	1115.53	0.000
21.00	22.71	1460.00	100.00	19.44	0.206	1334.62	0.000
25.00	24.34	1740.00	100.00	22.91	0.215	1593.86	0.000
30.00	26.18	2060.00	100.00	27.39	0.232	1893.25	0.000
36.00	28.24	2460.00	100.00	32.86	0.261	2251.13	0.000
43.00	30.50	2940.00	100.00	39.34	0.292	2689.31	0.000
51.00	32.89	3500.00	100.00	46.83	0.323	3207.80	0.000



# 17.3 Spodumene



### HELOS (H2634) & RODOS. R4: 0.5/1.8...350μm

$x_{10}$  = 2.28 μm       $x_{50}$  = 20.67 μm       $x_{90}$  = 61.56 μm      SMD = 6.72 μm

VMD = 26.96 μm

$x_{16}$  = 3.89 μm       $x_{84}$  = 51.39 μm       $x_{99}$  = 98.28 μm      SV = 0.89 m<sup>2</sup>/cm<sup>3</sup>

Sm = 2125.86 cm<sup>2</sup>/g

### Distribution sum

$x_0$ /μm	$Q_3$ /%	$x_0$ /μm	$Q_3$ /%	$x_0$ /μm	$Q_3$ /%	$x_0$ /μm	$Q_3$ /%
1.80	7.76	7.40	25.48	30.00	63.13	122.00	99.97
2.20	9.64	8.60	28.17	36.00	70.29	146.00	100.00
2.60	11.35	10.00	31.14	42.00	76.45	174.00	100.00
3.00	12.92	12.00	35.13	50.00	83.14	206.00	100.00
3.60	15.07	15.00	40.67	60.00	89.34	246.00	100.00
4.40	17.64	18.00	45.77	72.00	94.39	294.00	100.00
5.20	19.96	21.00	50.52	86.00	97.77	350.00	100.00
6.20	22.59	25.00	56.42	102.00	99.37		

Distribution density (log.)

$x_m/\mu\text{m}$	$q_3 \lg$	$x_m/\mu\text{m}$	$q_3 \lg$	$x_m/\mu\text{m}$	$q_3 \lg$	$x_m/\mu\text{m}$	$q_3 \lg$
0.95	0.14	6.77	0.38	27.39	0.85	111.55	0.08
1.99	0.22	7.98	0.41	32.86	0.90	133.46	0.00
2.39	0.24	9.27	0.45	38.88	0.92	159.39	0.00
2.79	0.25	10.95	0.50	45.83	0.88	189.33	0.00
3.29	0.27	13.42	0.57	54.77	0.78	225.11	0.00
3.98	0.30	16.43	0.64	65.73	0.64	268.93	0.00
4.78	0.32	19.44	0.71	78.69	0.44	320.78	0.00
5.68	0.34	22.91	0.78	93.66	0.22		

**HELOS (H2634) & RODOS. R4: 0.5/1.8...350 $\mu\text{m}$**

$x_{10}$	= 2.26 $\mu\text{m}$	$x_{50}$	= 20.52 $\mu\text{m}$	$x_{90}$	= 62.01 $\mu\text{m}$	SMD	= 6.67 $\mu\text{m}$
VMD	= 27.01 $\mu\text{m}$						
$x_{16}$	= 3.83 $\mu\text{m}$	$x_{84}$	= 51.53 $\mu\text{m}$	$x_{99}$	= 99.67 $\mu\text{m}$	SV	= 0.90 $\text{m}^2/\text{cm}^3$
Sm	= 2143.27 $\text{cm}^2/\text{g}$						

Distribution sum

$x_0/\mu\text{m}$	$Q_3/\%$	$x_0/\mu\text{m}$	$Q_3/\%$	$x_0/\mu\text{m}$	$Q_3/\%$	$x_0/\mu\text{m}$	$Q_3/\%$
1.80	7.85	7.40	25.74	30.00	63.30	122.00	99.95
2.20	9.76	8.60	28.43	36.00	70.38	146.00	100.00
2.60	11.49	10.00	31.38	42.00	76.46	174.00	100.00
3.00	13.08	12.00	35.36	50.00	83.07	206.00	100.00
3.60	15.26	15.00	40.91	60.00	89.17	246.00	100.00
4.40	17.86	18.00	46.01	72.00	94.13	294.00	100.00
5.20	20.20	21.00	50.77	86.00	97.53	350.00	100.00
6.20	22.84	25.00	56.64	102.00	99.25		

Distribution density (log.)

$x_m/\mu\text{m}$	$q_3 \lg$	$x_m/\mu\text{m}$	$q_3 \lg$	$x_m/\mu\text{m}$	$q_3 \lg$	$x_m/\mu\text{m}$	$q_3 \lg$
0.95	0.14	6.77	0.38	27.39	0.84	111.55	0.09
1.99	0.22	7.98	0.41	32.86	0.89	133.46	0.01
2.39	0.24	9.27	0.45	38.88	0.91	159.39	0.00
2.79	0.26	10.95	0.50	45.83	0.87	189.33	0.00
3.29	0.28	13.42	0.57	54.77	0.77	225.11	0.00
3.98	0.30	16.43	0.64	65.73	0.63	268.93	0.00
4.78	0.32	19.44	0.71	78.69	0.44	320.78	0.00
5.68	0.35	22.91	0.78	93.66	0.23		

**HELOS (H2634) & RODOS. R4: 0.5/1.8...350 $\mu\text{m}$**

$x_{10}$	= 2.25 $\mu\text{m}$	$x_{50}$	= 20.71 $\mu\text{m}$	$x_{90}$	= 61.76 $\mu\text{m}$	SMD	= 6.68 $\mu\text{m}$
VMD	= 27.05 $\mu\text{m}$						
$x_{16}$	= 3.84 $\mu\text{m}$	$x_{84}$	= 51.58 $\mu\text{m}$	$x_{99}$	= 98.65 $\mu\text{m}$	SV	= 0.90 $\text{m}^2/\text{cm}^3$
Sm	= 2138.92 $\text{cm}^2/\text{g}$						

Distribution sum

$x_0/\mu\text{m}$	$Q_3/\%$	$x_0/\mu\text{m}$	$Q_3/\%$	$x_0/\mu\text{m}$	$Q_3/\%$	$x_0/\mu\text{m}$	$Q_3/\%$
1.80	7.87	7.40	25.57	30.00	62.92	122.00	99.96
2.20	9.77	8.60	28.23	36.00	70.06	146.00	100.00
2.60	11.50	10.00	31.18	42.00	76.25	174.00	100.00
3.00	13.08	12.00	35.15	50.00	83.01	206.00	100.00
3.60	15.23	15.00	40.67	60.00	89.26	246.00	100.00
4.40	17.79	18.00	45.75	72.00	94.31	294.00	100.00
5.20	20.09	21.00	50.46	86.00	97.70	350.00	100.00
6.20	22.70	25.00	56.28	102.00	99.34		

Distribution density (log.)

$x_m/\mu\text{m}$	$q_3 \lg$	$x_m/\mu\text{m}$	$q_3 \lg$	$x_m/\mu\text{m}$	$q_3 \lg$	$x_m/\mu\text{m}$	$q_3 \lg$
0.95	0.14	6.77	0.37	27.39	0.84	111.55	0.08
1.99	0.22	7.98	0.41	32.86	0.90	133.46	0.00
2.39	0.24	9.27	0.45	38.88	0.93	159.39	0.00
2.79	0.25	10.95	0.50	45.83	0.89	189.33	0.00
3.29	0.27	13.42	0.57	54.77	0.79	225.11	0.00
3.98	0.29	16.43	0.64	65.73	0.64	268.93	0.00
4.78	0.32	19.44	0.70	78.69	0.44	320.78	0.00
5.68	0.34	22.91	0.77	93.66	0.22		

**HELOS (H2634) & RODOS. R5: 0.5/4.5...875 $\mu\text{m}$**

$x_{10}$	= 3.21 $\mu\text{m}$	$x_{50}$	= 24.52 $\mu\text{m}$	$x_{90}$	= 70.69 $\mu\text{m}$	SMD	= 9.67 $\mu\text{m}$
VMD	= 31.46 $\mu\text{m}$						
$x_{16}$	= 4.95 $\mu\text{m}$	$x_{84}$	= 58.69 $\mu\text{m}$	$x_{99}$	= 118.41 $\mu\text{m}$	SV	= 0.62 $\text{m}^2/\text{cm}^3$
Sm	= 1478.08 $\text{cm}^2/\text{g}$						

Distribution sum

$x_0/\mu\text{m}$	$Q_3/\%$	$x_0/\mu\text{m}$	$Q_3/\%$	$x_0/\mu\text{m}$	$Q_3/\%$	$x_0/\mu\text{m}$	$Q_3/\%$
4.50	14.77	18.50	41.60	75.00	91.87	305.00	100.00
5.50	17.53	21.50	45.88	90.00	95.86	365.00	100.00
6.50	20.04	25.00	50.66	105.00	98.10	435.00	100.00
7.50	22.37	30.00	57.14	125.00	99.44	515.00	100.00
9.00	25.58	37.50	66.04	150.00	99.97	615.00	100.00
11.00	29.46	45.00	73.71	180.00	100.00	735.00	100.00
13.00	33.00	52.50	80.03	215.00	100.00	875.00	100.00
15.50	37.07	62.50	86.44	255.00	100.00		

Distribution density (log.)

$x_m/\mu\text{m}$	$q_3 \lg$	$x_m/\mu\text{m}$	$q_3 \lg$	$x_m/\mu\text{m}$	$q_3 \lg$	$x_m/\mu\text{m}$	$q_3 \lg$
1.50	0.15	16.93	0.59	68.47	0.69	278.88	0.00
4.97	0.32	19.94	0.66	82.16	0.50	333.65	0.00
5.98	0.35	23.18	0.73	97.21	0.33	398.47	0.00
6.98	0.37	27.39	0.82	114.56	0.18	473.31	0.00
8.22	0.41	33.54	0.92	136.93	0.07	562.78	0.00
9.95	0.45	41.08	0.97	164.32	0.00	672.33	0.00
11.96	0.49	48.61	0.94	196.72	0.00	801.95	0.00
14.20	0.53	57.28	0.85	234.15	0.00		