

Supporting Information

Design and synthesis of dinuclear cobalt(II) complexes derived from strong π -acidic ligands: crystal structure and studies on the oxidation of sp^3 C–H bond

Anshu Singh, Bishal Boro, Ankur Maji, Ovender Singh, Sain Singh, U.P. Singh and Kaushik Ghosh ^{a*}

^aDepartment of Chemistry, Indian Institute of Technology Roorkee, Roorkee-247667 Uttarakhand, India
E-mail: kaushik.ghosh@cy.iitr.ac.in, ghoshfcy@iitr.ac.in, Tel (91)01332-285547, Fax: (91) 01332- 273560.

Table of Contents

1.	Comparison of bond lengths of crystal structure.
2.	Data comparison with literature for the oxidation of different substrates.
Fig. S1	¹ H NMR spectrum of L ¹ taking CDCl ₃ as solvent.
Fig. S2	¹³ C NMR spectrum of L ¹ taking CDCl ₃ as solvent.
Fig. S3	¹ H NMR spectrum of L ² taking DMSO as solvent.
Fig. S4	¹³ C NMR spectrum of L ² taking DMSO as solvent.
Fig. S5	Electronic absorption spectra of ligands L ¹ and complex 1 in dichloromethane solution.
Fig. S6	Electronic absorption spectra of ligands L ² and complex 2 in dichloromethane solution.
Table S1	Characteristic UV-visible spectroscopic data for ligands (L ¹ and L ²) and their cobalt (II) complexes (1-2).
Fig. S7	FT-IR spectrum of free ligand L ¹ .
Fig. S8	FT-IR spectrum of free ligand L ² .
Fig. S9	FT-IR spectrum of complex 1 .
Fig. S10	FT-IR spectrum of complex 2 .
Fig. S11	ESI-MS Spectrum of L ¹ using acetonitrile as solvent.
Fig. S12	ESI-MS Spectrum of L ² using acetonitrile as solvent.
Fig. S13	ESI-MS spectra of complex 1 using acetonitrile as solvent.
Fig. S14	ESI-MS spectra of complex 2 using acetonitrile as solvent.
Table S2	Crystal data and structural refinement parameters for complex 1 .
Table S3	Selected bond angles and bond distances of complex 1 .
Scheme S1	Oxidation of fluorene.
Table S4	Oxidation of fluorene using different type complexes (1-2)
Fig. S15	Oxidation of fluorene using different type complexes (1-2)
Table S5	Effect of different oxidants on the oxidation of fluorene using Complex 1 .
Fig. S16	Effect of different oxidants on the oxidation of fluorene using Complex 1
Table S6	Varying amount of Complex 1 .

Fig. S17	Varying amount of Complex 1 .
Table S7	Varying amount of oxidant TBHP with constant amount of Complex 1 .
Fig. S18	Varying amount of oxidant TBHP with constant amount of Complex 1 .
Table S8	Effect of temperature on the oxidation of fluorene using Complex 1 .
Fig. S19	Effect of temperature on the oxidation of fluorene using Complex 1 .
Table S9	Effect of solvent on the oxidation of fluorene using Complex 1 .
Fig. S20	Effect of solvent on the oxidation of fluorene using Complex 1 .
Table S10	Oxidation of fluorene at different time using Complex 1 .
Fig. S21	Oxidation of fluorene at different time using Complex 1 .
Fig. S22-S37	^1H NMR and ^{13}C NMR spectrum of 1-8 taking CDCl_3 as solvent.
Table S11	Data analysis for oxidation of cyclohexane ^a
Table S12	Data analysis for oxidation of phenylacetonitrile ^a
Table S13	Data analysis for oxidation of 9,10-dihydroanthracene ^a
Table S14	Data analysis for oxidation of adamantane ^a
Fig. S38	GC-MS spectra for oxidation of cyclohexane.
Fig. S39	GC-MS spectra for oxidation of phenylacetonitrile.
Fig. S40	GC-MS spectra for oxidation of 9,10-dihydro anthracene.
Fig. S41	GC-MS spectra for oxidation of adamantane.
Fig. S42	Packing diagram of complex 1 (projection at c^* -axis).
Table S15	Comparative study of literature for the oxidation of different alkanes

1. Comparison of bond lengths of crystal structure

For complex **1** Co1A–N_{py} is close to the 2.043(1) Å. The bond length Co1A–N_{py} of complex **1** is in good agreement with our previous reported values¹ and Qian Co-workers², but smaller than the values reported by Nayab and co-workers³ and larger than the values reported by Batisa and co-workers.⁴ Co1A–N_{im} is close to 2.2008(9) Å. The bond length Co1A–N_{im} of complex **1** is smaller than our previous reported values Qian and co-workers² and larger than the values reported by Batisa and co-workers. Co1A–Cl1A and Co1A–Cl2A is close to the 2.2867(3) Å and 2.3064(4) Å is in good agreement with our previous reported value⁵ and Nayab and co-workers⁶ but smaller than the values reported by Batisa and co-workers.⁴ Qian and co-workers.² Co1A–O1A is close to the 2.0842(9) Å is in good agreement with Ali and co-workers⁷ but smaller than the values reported by Jacewicz and co-workers.⁸ The bond length of complex **1** were consistent with reported data of high spin Co(II) complexes.⁵

2. Data comparison with literature for the oxidation of different substrates

We compared the catalytic activity in the light of the reported literature. In our study, catalyst **1** provided the best result for the oxidation of sp³ C–H bond under optimized reaction condition. Results obtained after catalysis were compared with the literature reports (shown in Table S15). The product formation for fluorene and diphenyl methane was excellent (80%) for catalysts **1–2** and it was efficient as compared to literature reports^{9,10} whereas less efficient for the catalytic oxidation of adamantane as compared to previous reports.¹¹ The product formation were good (>73%) for ethyl benzene as well as substituted ethyl benzene compared to previous literature reports.¹² Catalyst **1-2** showed good catalytic activity for cyclohexane and tetralin compared to other reports.¹³⁻¹⁴ Thus, the present complexes may be placed among good catalysts known for oxidation of benzylic as well as aliphatic sp³ C–H bond.

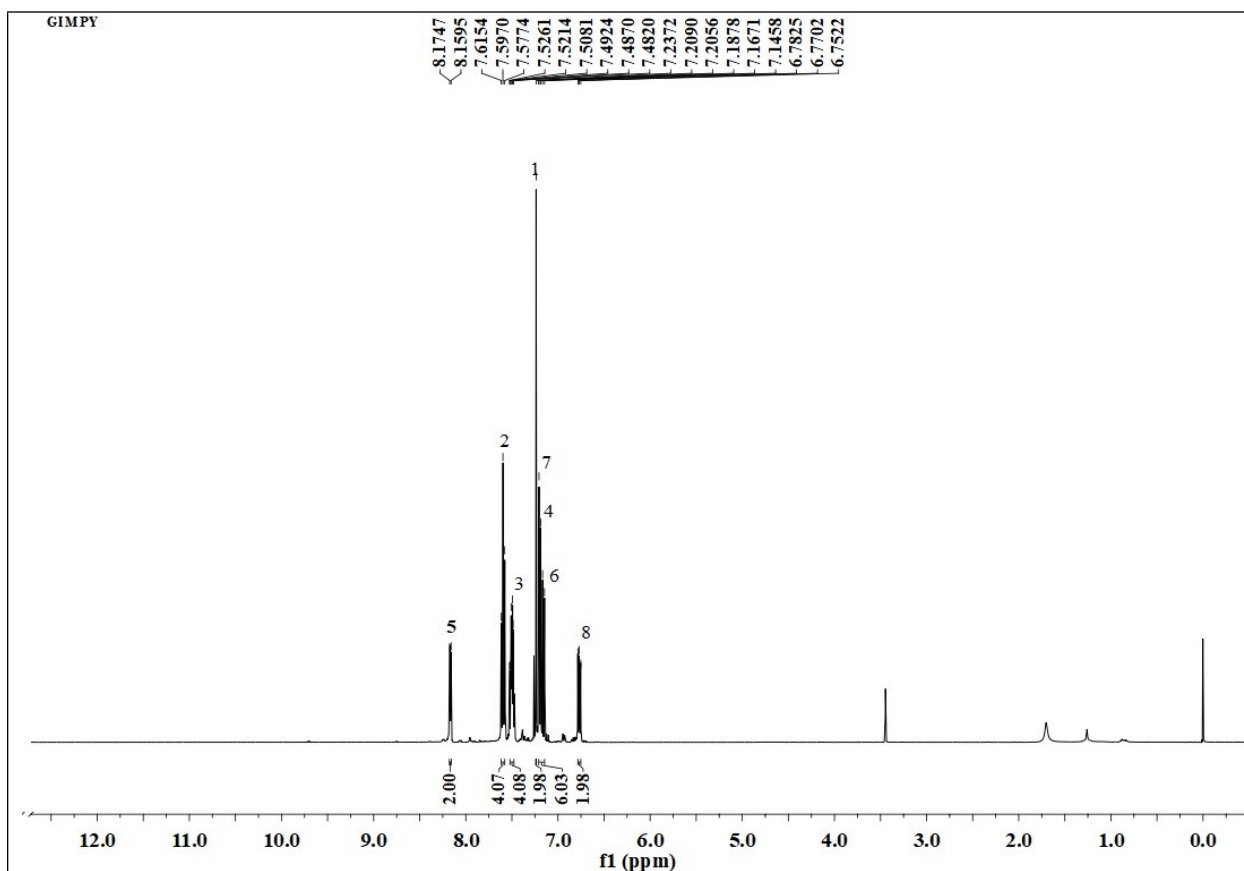


Fig. S1. ^1H NMR spectrum of L^1 taking CDCl_3 as solvent.

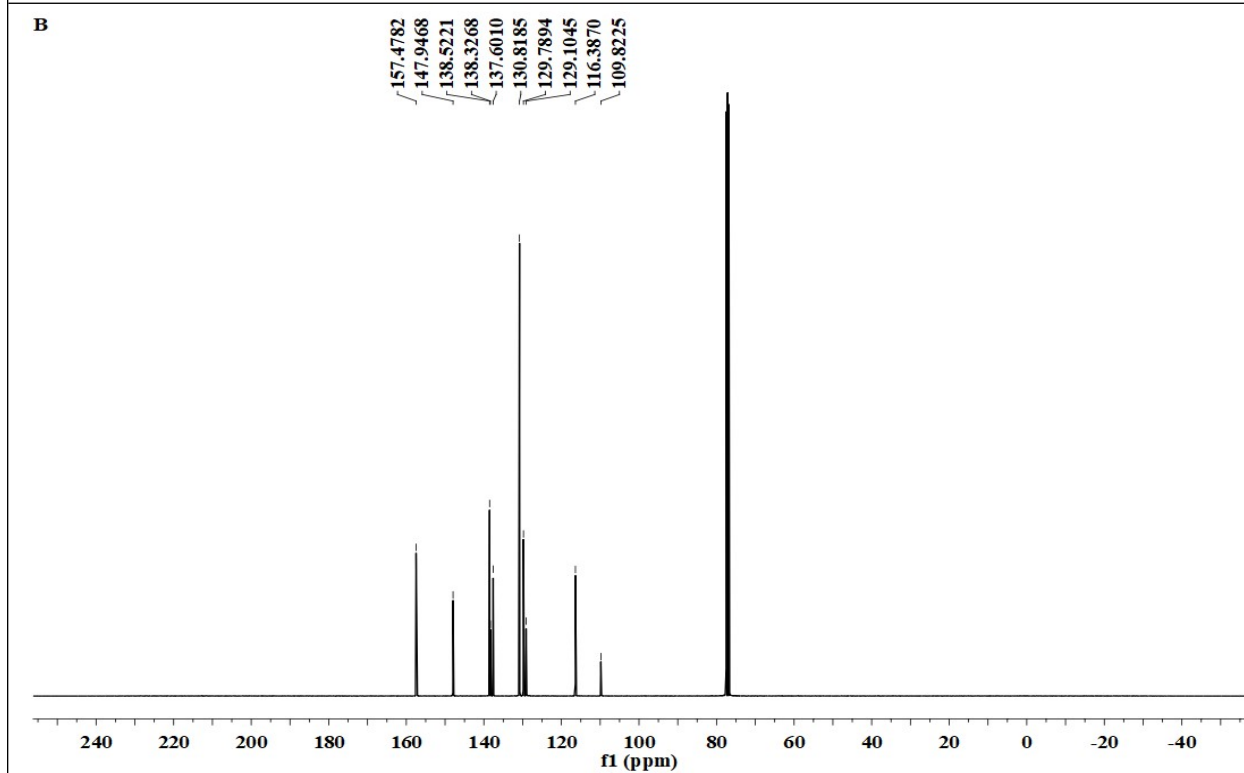


Fig. S2. ^{13}C NMR spectrum of L^1 taking CDCl_3 as solvent.

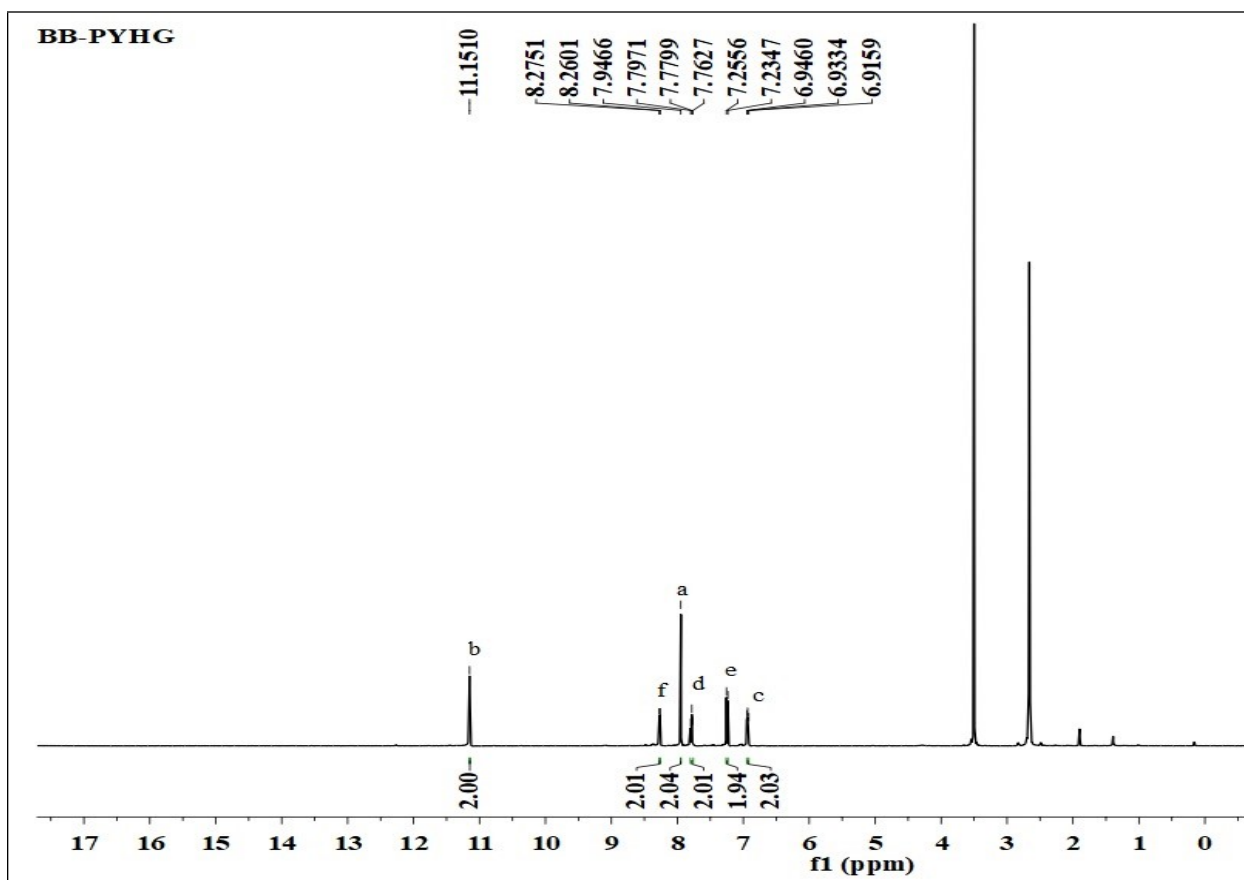


Fig. S3. ^1H NMR spectrum of L^2 taking DMSO as solvent.

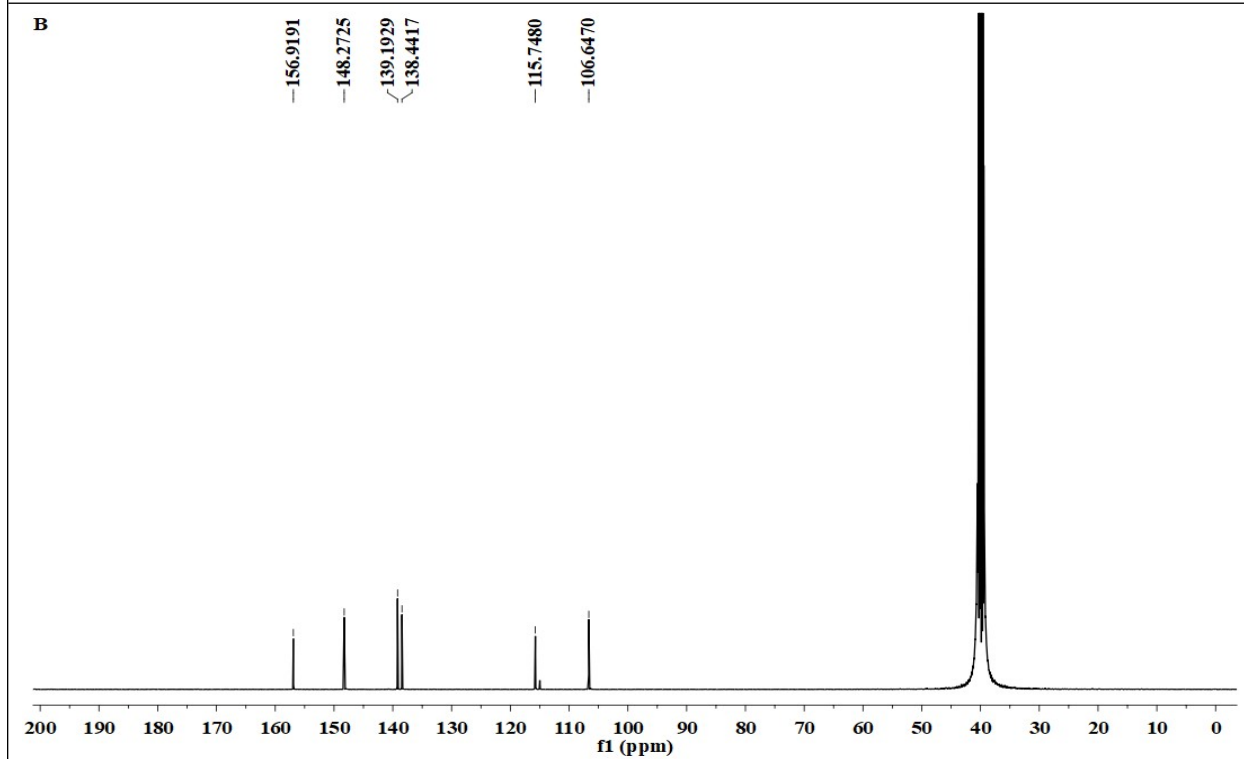


Fig. S4. ^{13}C NMR spectrum of L^2 taking DMSO as solvent.



Fig. S5. Electronic absorption spectra of ligands L^1 and complex **1** in dichloromethane solution.

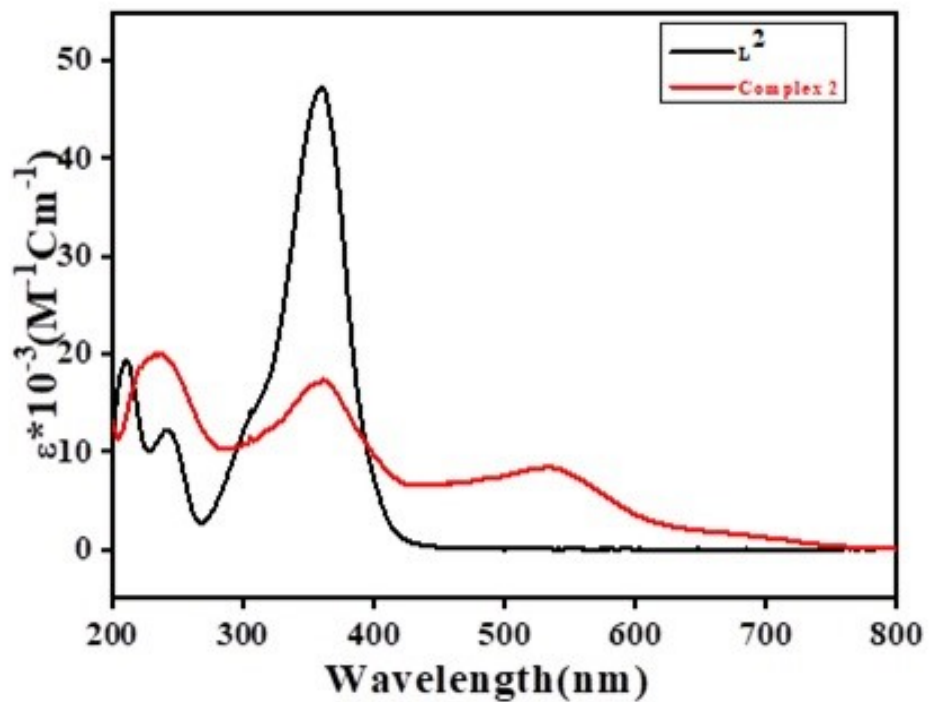


Fig. S6. Electronic absorption spectra of ligands L^2 and complex **2** in dichloromethane solution.

Table S1: Characteristic UV-visible spectroscopic data for ligands (L^1 and L^2) and their cobalt (II) complexes (**1-2**).

Entry	Compound	λ_{\max} (nm)	ϵ ($M^{-1}cm^{-1}$)
1	L^1	227, 284, 361	11237, 7775, 33325
2	L^2	210, 241, 358	18257, 12536, 45525
3	Complex 1	235, 304, 415	5100, 3037, 3450
4	Complex 2	245, 362, 515	19452, 15650, 9650

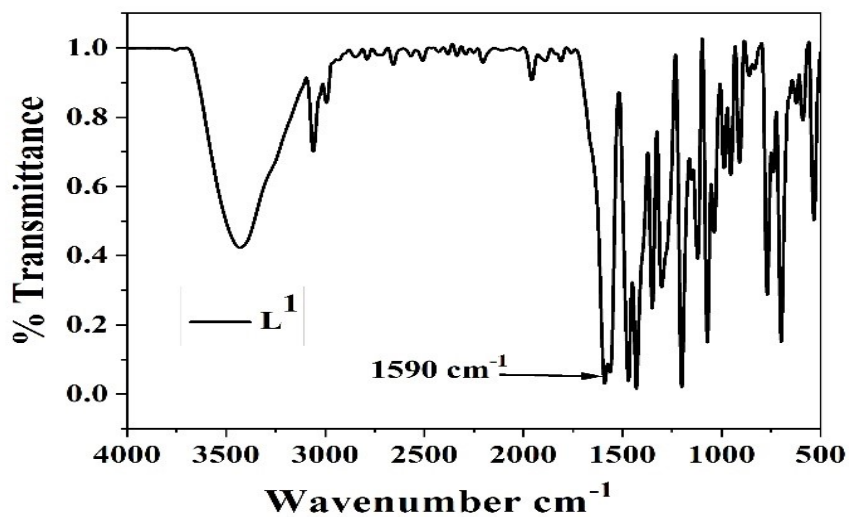


Fig. S7. FT-IR spectrum of free ligand L¹.

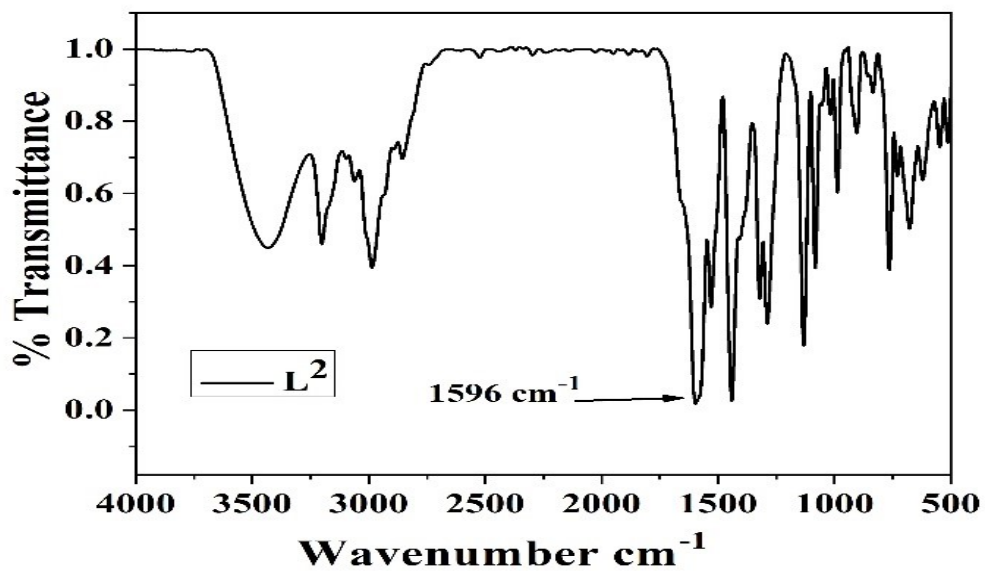


Fig. S8. FT-IR spectrum of free ligand L².

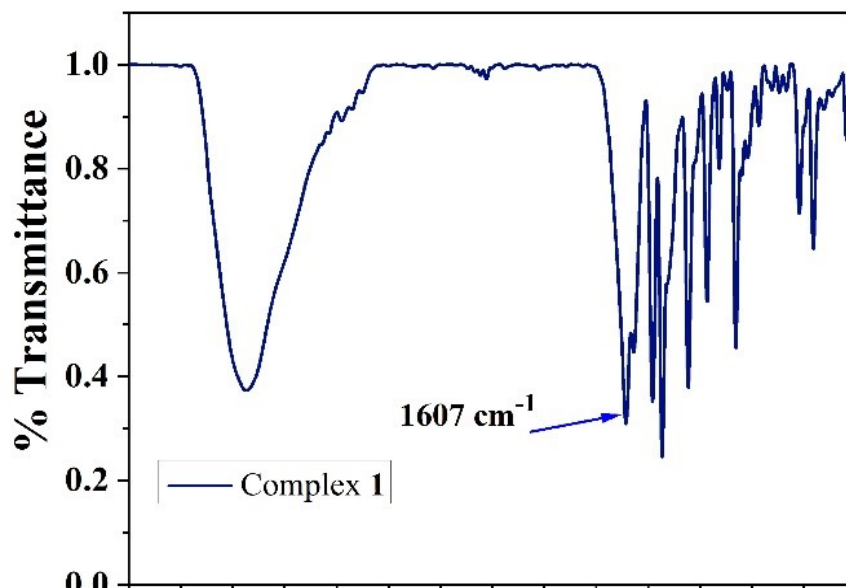


Fig. S9. FT-IR spectrum of complex 1.

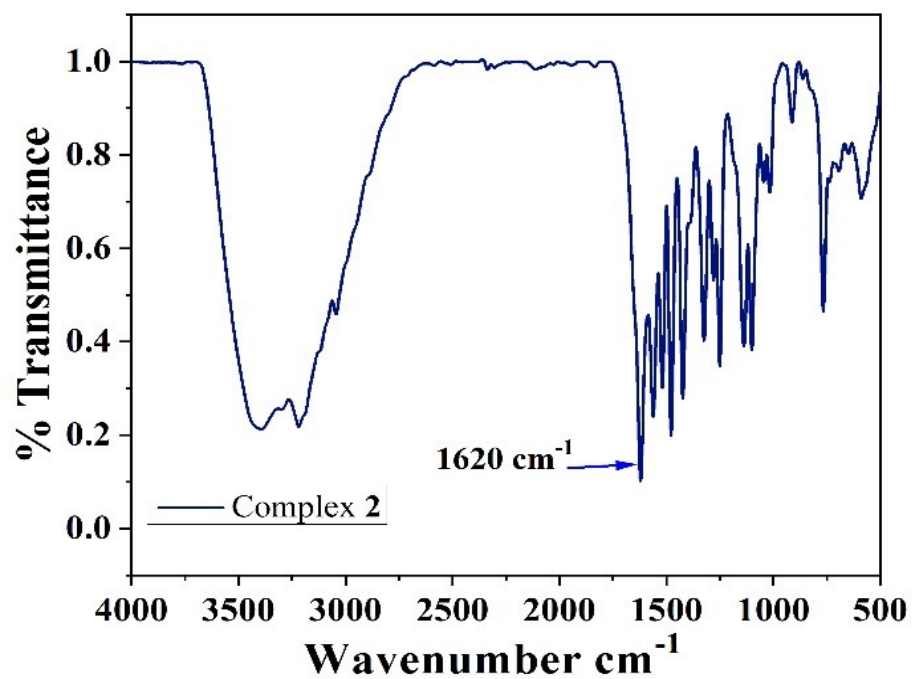


Fig. S10. FT-IR spectrum of complex 2.

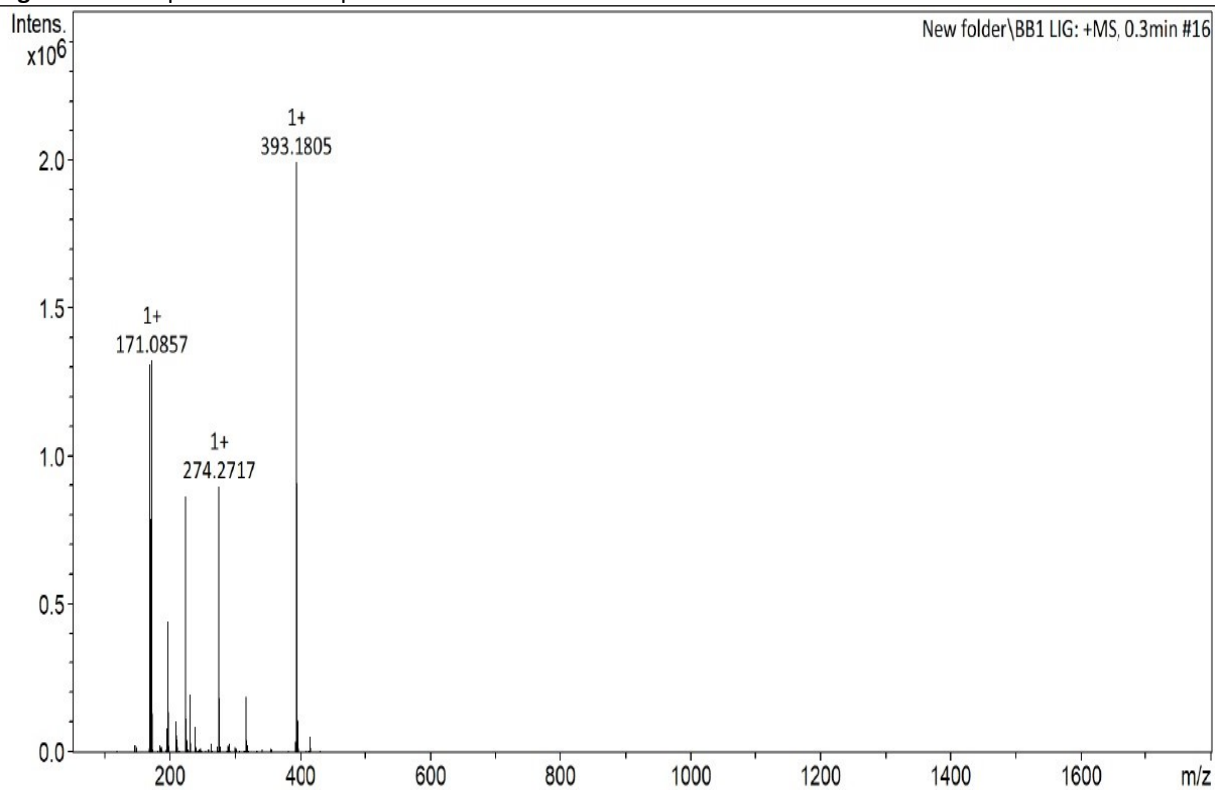


Fig. S11. ESI-MS Spectrum of L¹ using acetonitrile as solvent.

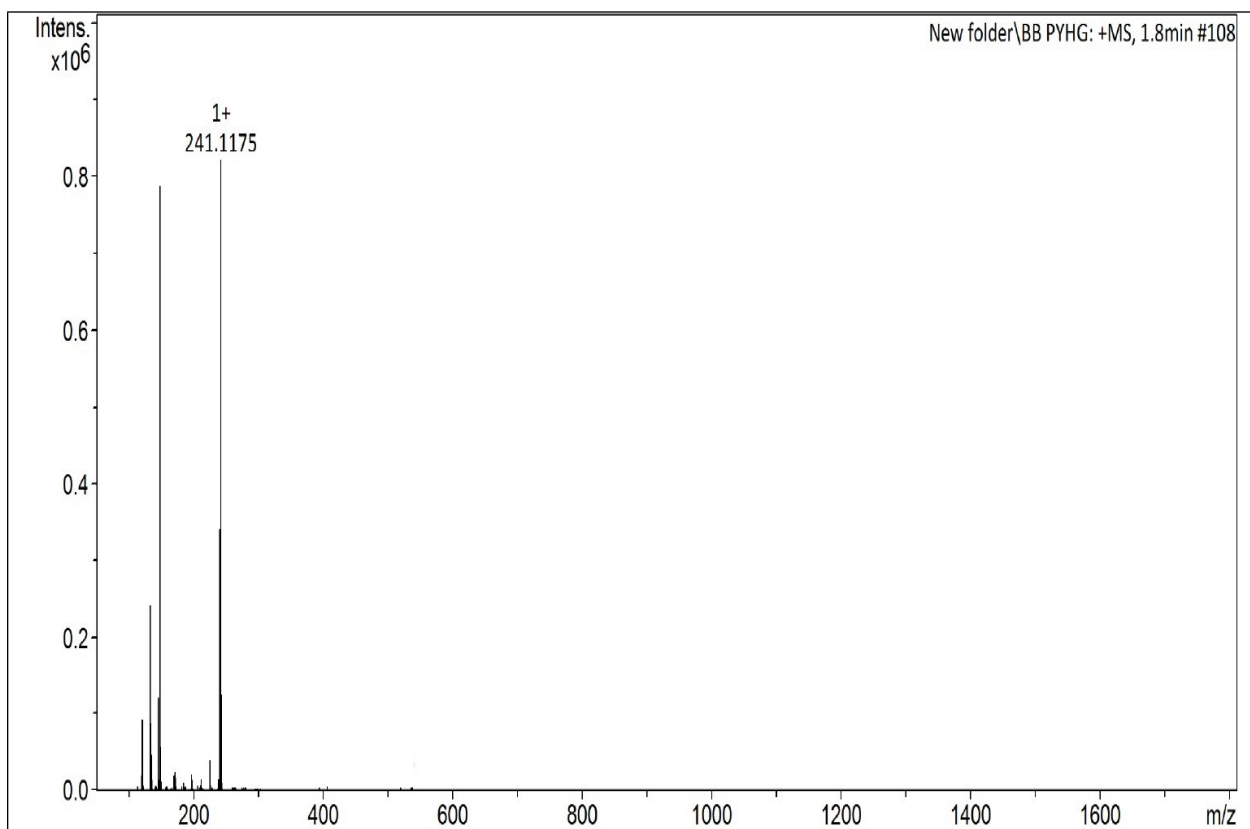


Fig. S12. ESI-MS Spectrum of L² using acetonitrile as solvent.

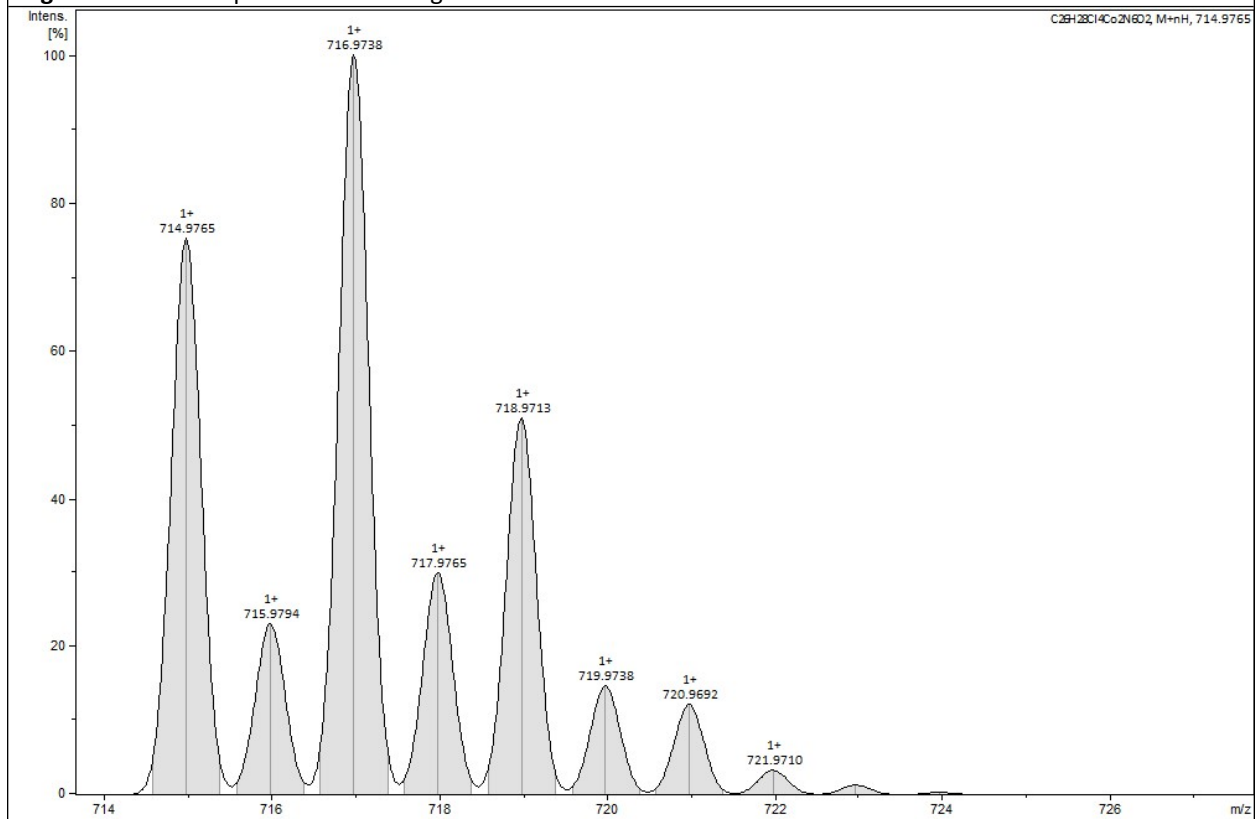


Fig. S13. ESI-MS spectra of complex **1** using acetonitrile as solvent.

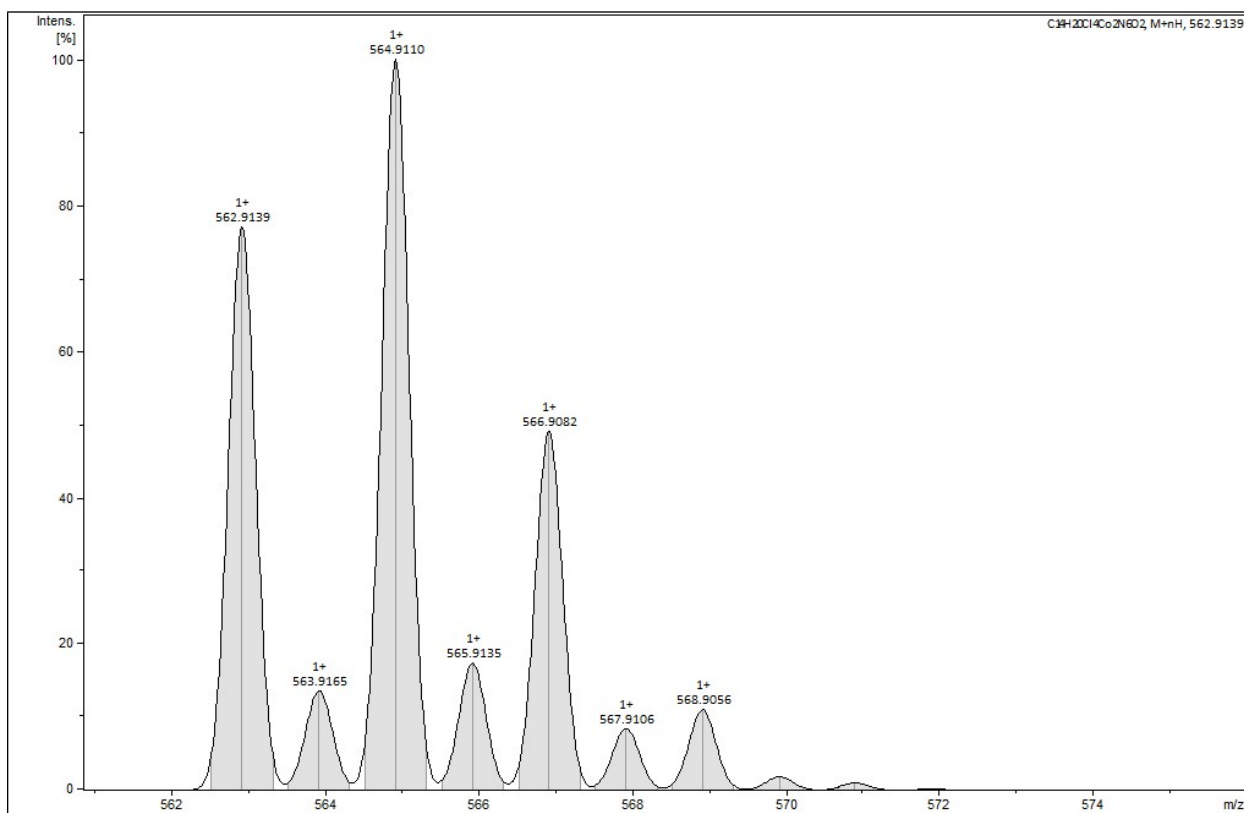


Fig. S14. ESI-MS spectra of complex **2** using acetonitrile as solvent.

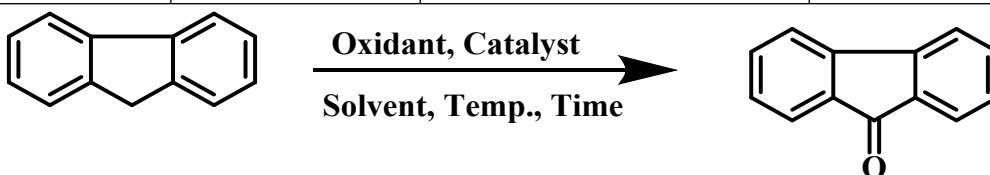
Table S2: Crystal data and structural refinement parameters for complex **1**

Empirical formula	C₂₆Cl₄Co₂N₈HO
Formula weight	716.20
Temperature/K	100.0
Color	Metallic
Crystal system	triclinic
Space group	P-1
a/Å	9.1270(3)
b/Å	9.5751(3)
c/Å	9.8287(3)
α/°	65.8370(10)
β/°	70.6870(10)
γ/°	89.6210(10)
Volume/Å ³	731.27(4)
Z	1
ρ _{calc} /cm ³	1.626
μ/mm ⁻¹	1.536
F(000)	364.0
Crystal size/mm ³	0.177 × 0.051 × 0.021
Radiation	MoKα (λ = 0.71073)
2θ range for data collection/°	4.716 to 61.248
Index ranges	-13 ≤ h ≤ 13, -13 ≤ k ≤ 13, -14 ≤ l ≤ 14
Reflections collected	36244
Independent reflections	4500 [R _{int} = 0.0299, R _{sigma} = 0.0164]
Data/restraints/parameters	4500/3/185

Goodness-of-fit on F ²	1.065
Final R indexes [$l \geq 2\sigma(l)$]	R ₁ = 0.0245, wR ₂ = 0.0630
Final R indexes [all data]	R ₁ = 0.0262, wR ₂ = 0.0644
Largest diff. peak/hole / e Å ⁻³	0.65/-0.29
^a GOF = $[\sum[w(F_o^2 - F_c^2)^2] / (M - N)]^{1/2}$ (M = number of reflections, N = number of parameters refined). ^b R ₁ = $\sum F_o - F_c / \sum F_o $, ^c wR ₂ = $[\sum[w(F_o^2 - F_c^2)_2] / \sum [w(F_o)_2]]^{1/2}$	

Table S3: Selected bond distances and bond angles of complex 1

Bond Lengths (Å)		Bond Angles(°)	
Co1A—Cl1A	2.2867(3)	Cl1A—Co1A—Cl2A	130.07(1)
Co1A—Cl2A	2.3064(4)	O1A—Co1A—Cl1A	94.55(3)
Co1A—O1A	2.0842(9)	N2 —Co1A —Cl1A	86.42(3)
Co1A—N2	2.2008(9)	Cl1A—Co1A —N1	111.04(3)
Co1A—N1	2.043(1)	Cl2A—Co1A —O1A	90.01(3)
		Cl2A—Co1A —N2	93.75(3)
		Cl2A —Co1A —N1	117.38(3)
		O1A —Co1A —N2	174.19(4)
		O1A —Co1A —N1	98.38(4)
		N2 —Co1A —N1	75.95(4)



Scheme S1: Oxidation of fluorene

^aAll reactions were carried out in CH₃CN at 60 °C. **Catalysts** (0.04 mmol), alkanes (1 mmol), and TBHP (8 mmol).

^bTON = mmol of product/mmol of catalyst loading

^cTOF = TON / time (in hours).

Table S4: Oxidation of fluorene using different type complexes (1-2)

Complex	% Yield
Co ₂ (L ¹)(H ₂ O) ₂ Cl ₄ (1)	94
Co ₂ (L ²)(H ₂ O) ₂ Cl ₄ (2)	91
Ligands	Trace
CoCl ₂ ·6H ₂ O	Trace

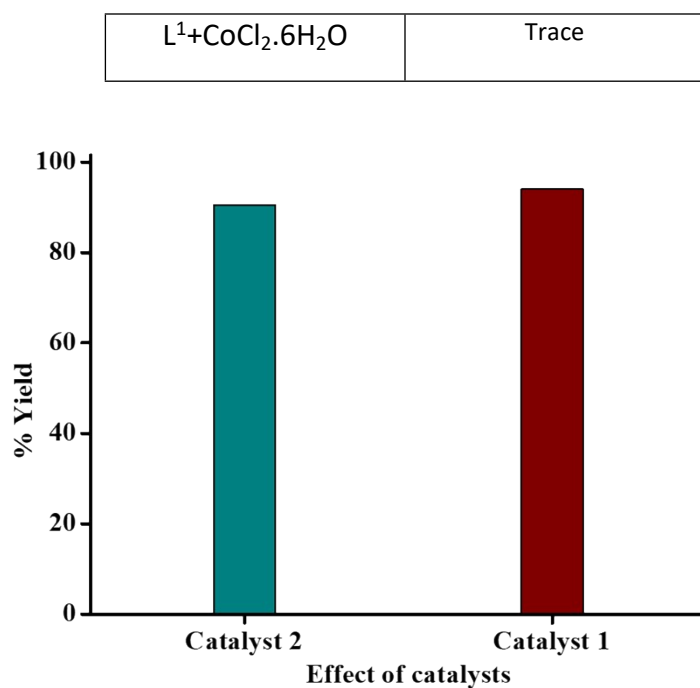


Fig. S15. Oxidation of fluorene using different type complexes (1-2)

Table S5: Effect of different oxidants on the oxidation of fluorene using Complex 1.

Entry	Substrate	Amount (mmol)			Solvent	% Yield
		Fluorene	Complex 1	Oxidant		
1	Fluorene	1	0.04	TBHP(8)	CH ₃ CN	94
2	Fluorene	1	0.04	H ₂ O ₂ (8)	CH ₃ CN	41
3	Fluorene	1	0.04	mCPBA(8)	CH ₃ CN	20

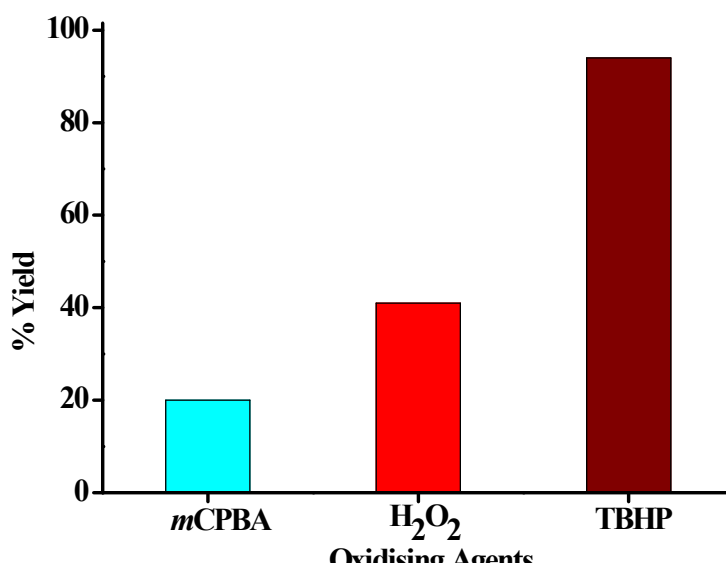


Fig. S16. Effect of different oxidants on the oxidation of fluorene using **Complex 1**

Table S6: Varying amount of Complex 1 .						
Entry	Substrate	Amount (mmol)			Solvent	% Yield
		Fluorene	Complex 1	TBHP		
1	Fluorene	1	0.01	8	CH ₃ CN	18%
2	Fluorene	1	0.02	8	CH ₃ CN	42%
3	Fluorene	1	0.03	8	CH ₃ CN	58%
4	Fluorene	1	0.04	8	CH ₃ CN	94%
5	Fluorene	1	0.05	8	CH ₃ CN	94%

Note: All the data was recorded after 12 h

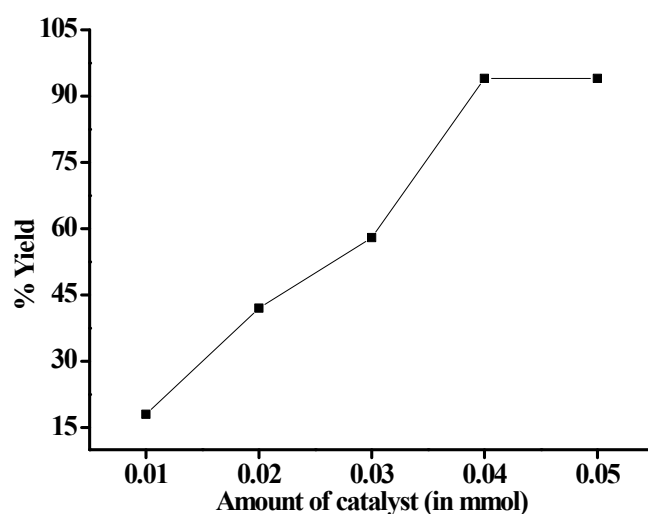


Fig. S17. Varying amount of **Complex 1**.

Table S7: Varying amount of oxidant TBHP with constant amount of Complex 1 .						
Entry	Substrate	Amount (mmol)			Solvent	% Yield
		Fluorene	Complex 1	TBHP		
1	Fluorene	1	0.04	2	CH ₃ CN	15%
2	Fluorene	1	0.04	4	CH ₃ CN	34%
3	Fluorene	1	0.04	6	CH ₃ CN	72%
4	Fluorene	1	0.04	8	CH ₃ CN	94%
5	Fluorene	1	0.04	10	CH ₃ CN	94%

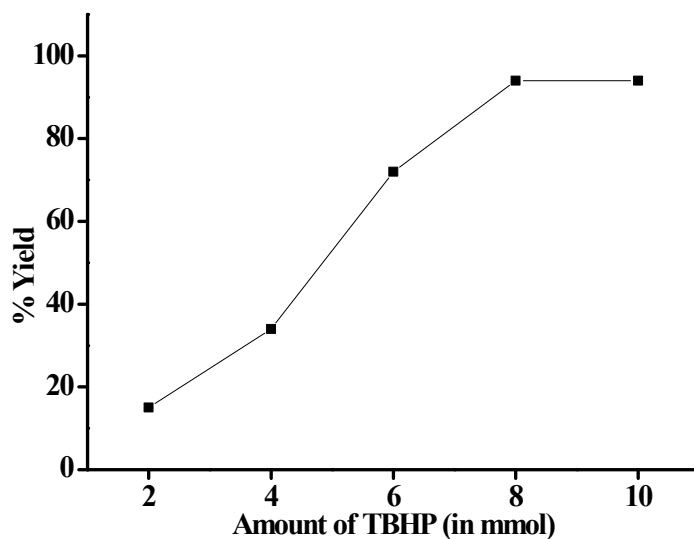


Fig. S18. Varying amount of oxidant TBHP with constant amount of Complex 1.

Entry	Substrate	Amount (mmol)			Temp °C	% Yield
		Fluorene	Complex 1	TBHP		
1	Fluorene	1	0.04	8	0	0
2	Fluorene	1	0.04	8	20	5
3	Fluorene	1	0.04	8	40	45
4	Fluorene	1	0.04	8	60	61
5	Fluorene	1	0.04	8	80	94

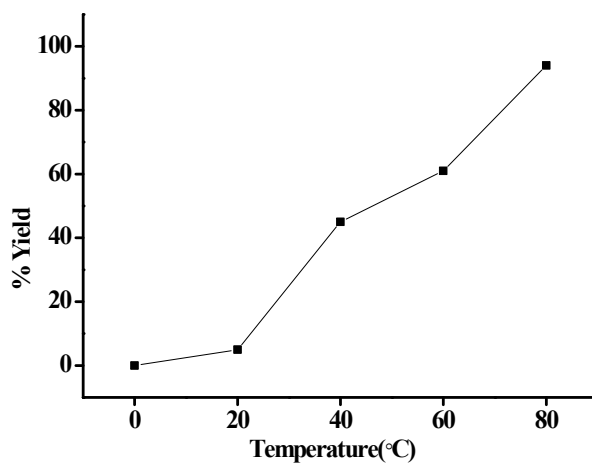


Fig. S19. Effect of temperature on the oxidation of fluorene using Complex 1

Table S9: Effect of solvent on the oxidation of fluorene using Complex 1.

Entry	Substrate	Amount (mmol)			Solvent	% Yield
		Fluorene	Complex 1	TBHP		
1	Fluorene	1	0.04	8	CH ₃ CN	94
2	Fluorene	1	0.04	8	CH ₃ OH	20
3	Fluorene	1	0.04	8	Xylene	38
4	Fluorene	1	0.04	8	Benzene	47
5	Fluorene	1	0.04	8	Toluene	58
6	Fluorene	1	0.04	8	DMSO	52
7	Fluorene	1	0.04	8	DMF	42
8	Fluorene	1	0.04	8	THF	12
9	Fluorene	1	0.04	8	DCM	22

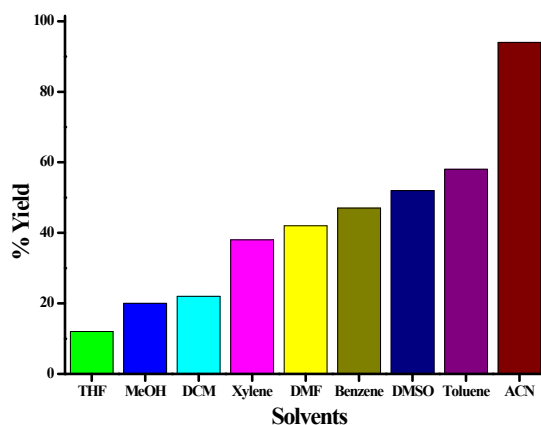


Fig. S20. Effect of solvent on the oxidation of fluorene using **Complex 1**.

Entry	Substrate	Time (h)	Solvent	% Yield
1	Fluorene	1	CH ₃ CN	8
2	Fluorene	2	CH ₃ CN	12
3	Fluorene	3	CH ₃ CN	16
4	Fluorene	4	CH ₃ CN	22
5	Fluorene	5	CH ₃ CN	26
6	Fluorene	6	CH ₃ CN	32
7	Fluorene	7	CH ₃ CN	44
8	Fluorene	8	CH ₃ CN	51
9	Fluorene	9	CH ₃ CN	57
10	Fluorene	10	CH ₃ CN	72
11	Fluorene	11	CH ₃ CN	82
12	Fluorene	12	CH ₃ CN	94

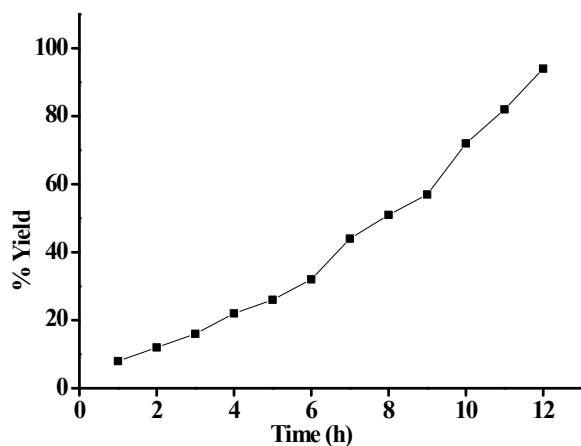


Fig. S21. Oxidation of fluorene at different time using **Complex 1**.

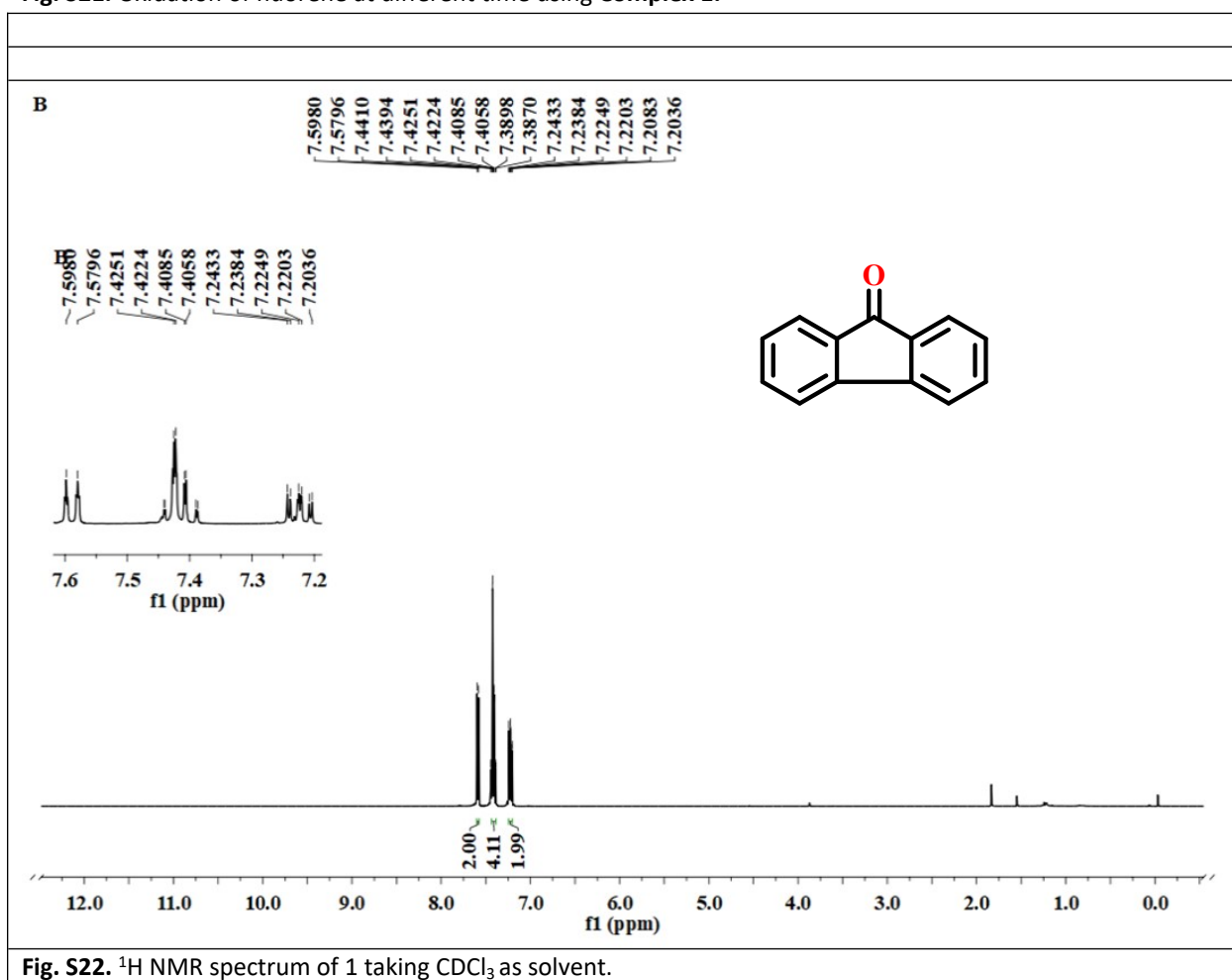


Fig. S22. ¹H NMR spectrum of **1** taking CDCl₃ as solvent.

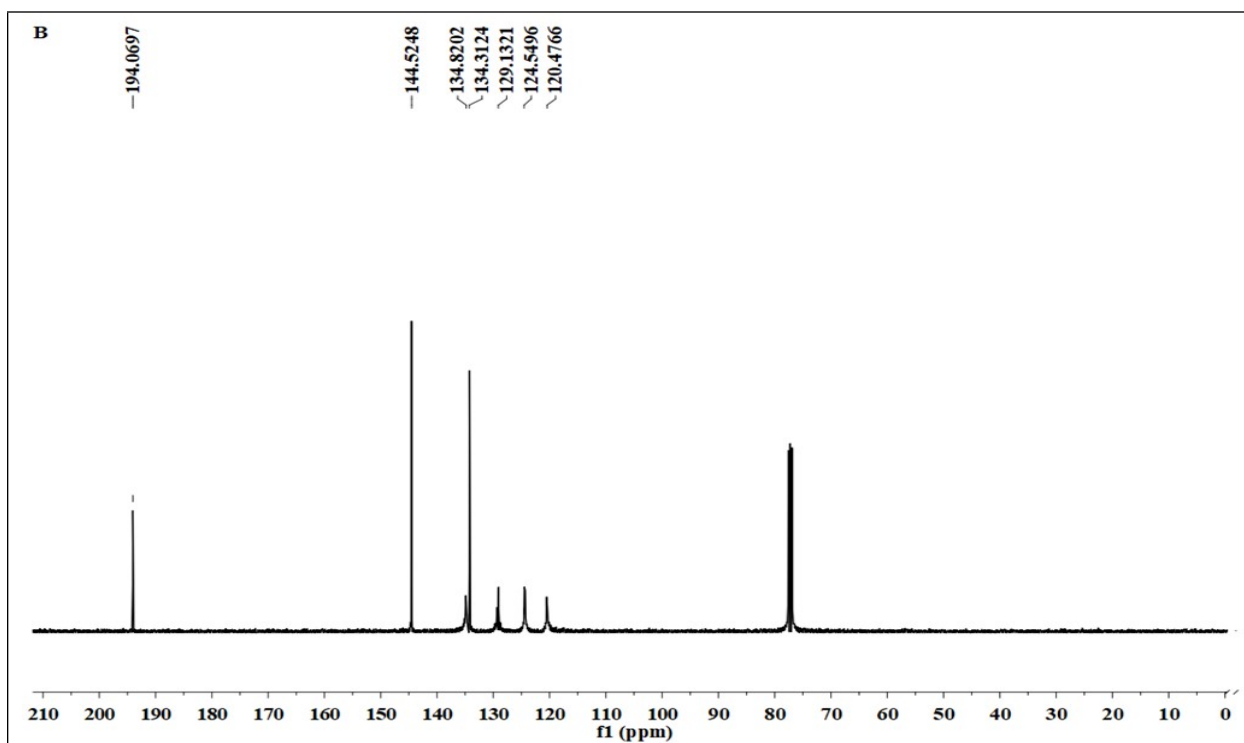


Fig. S23. ^{13}C NMR spectrum of 1 taking CDCl_3 as solvent.

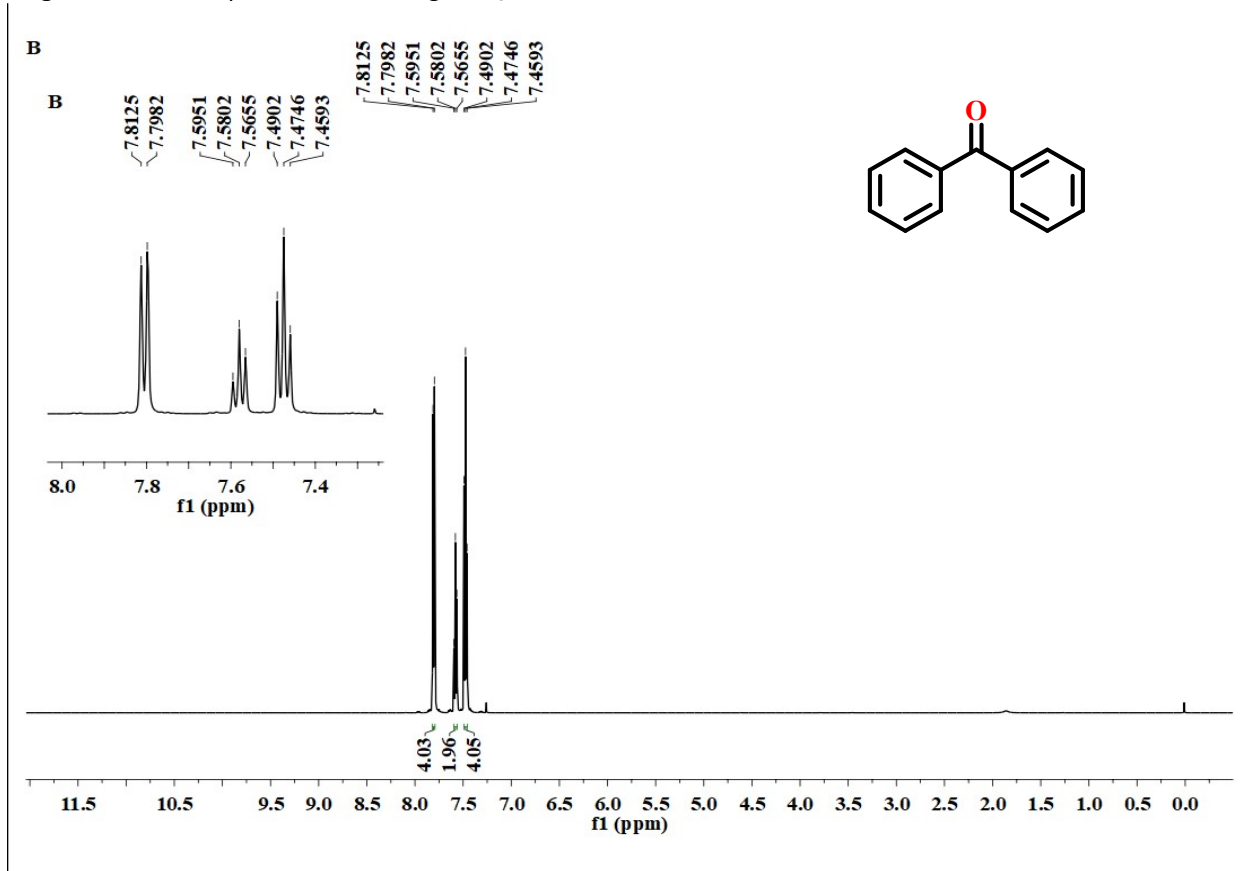


Fig. S24. ^1H NMR spectrum of 2 taking CDCl_3 as solvent.

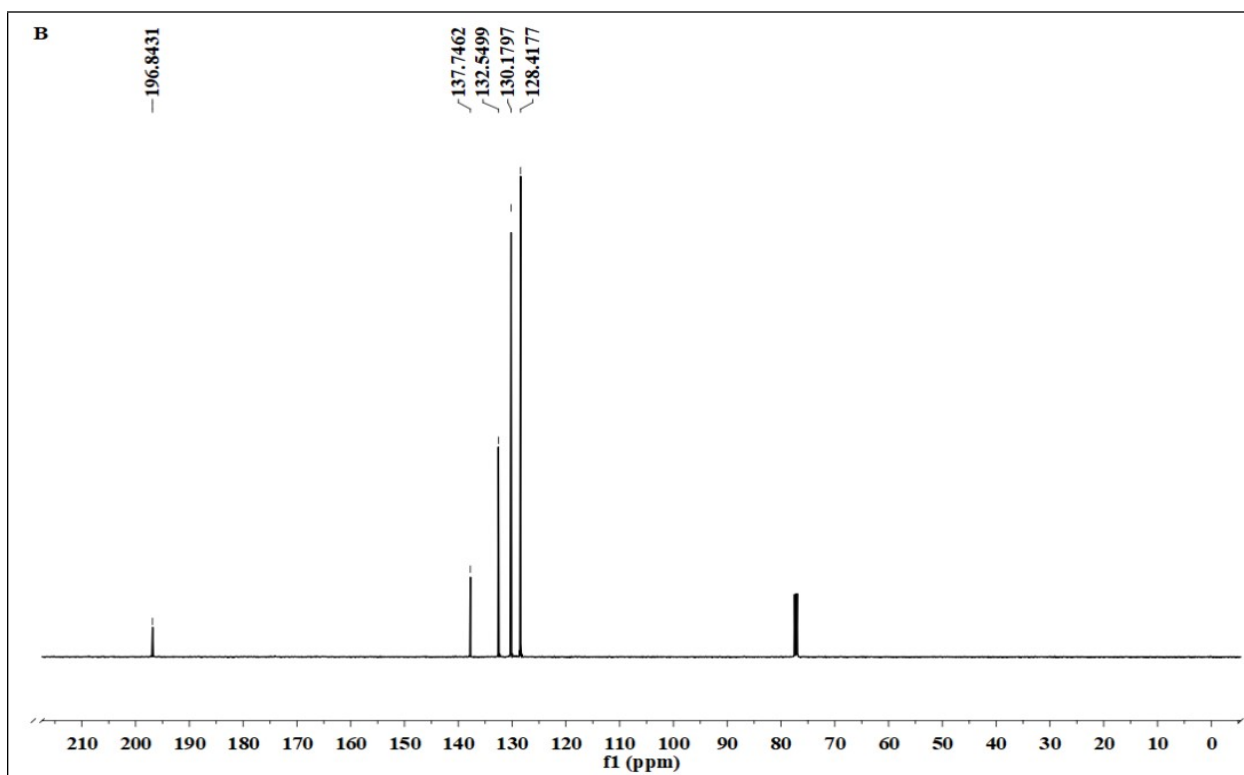


Fig. S25. ^{13}C NMR spectrum of 2 taking CDCl_3 as solvent.

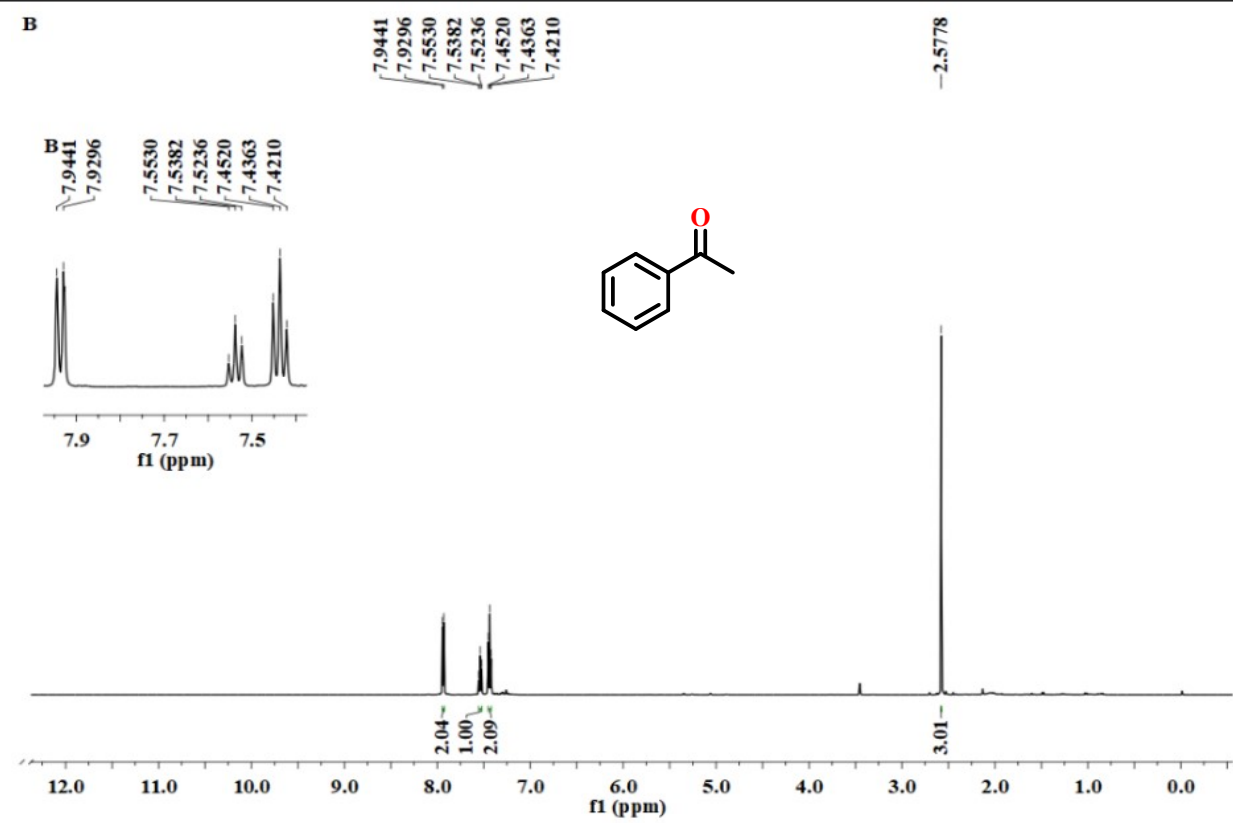


Fig. S26. ^1H NMR spectrum of 3 taking CDCl_3 as solvent.



Fig. S27. ^{13}C NMR spectrum of 3 taking CDCl_3 as solvent.

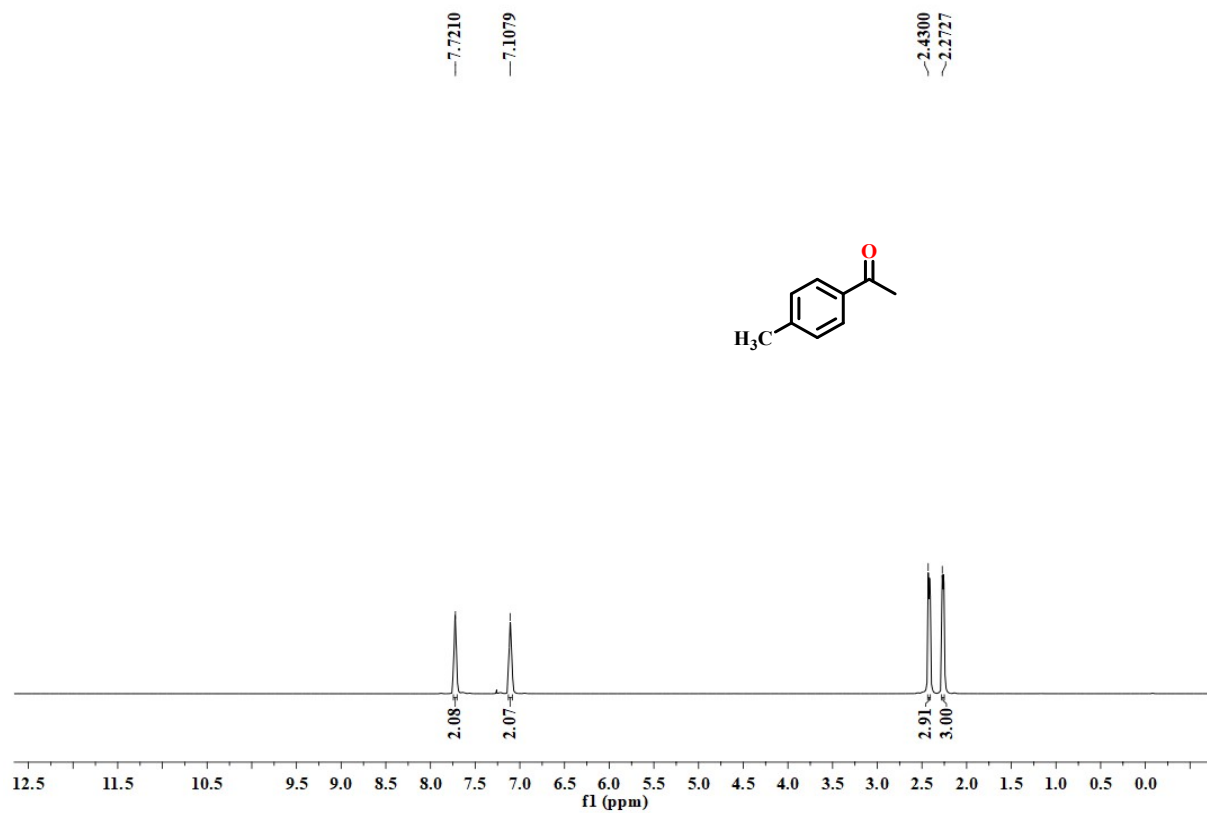


Fig. S28. ^1H NMR spectrum of 4 taking CDCl_3 as solvent.

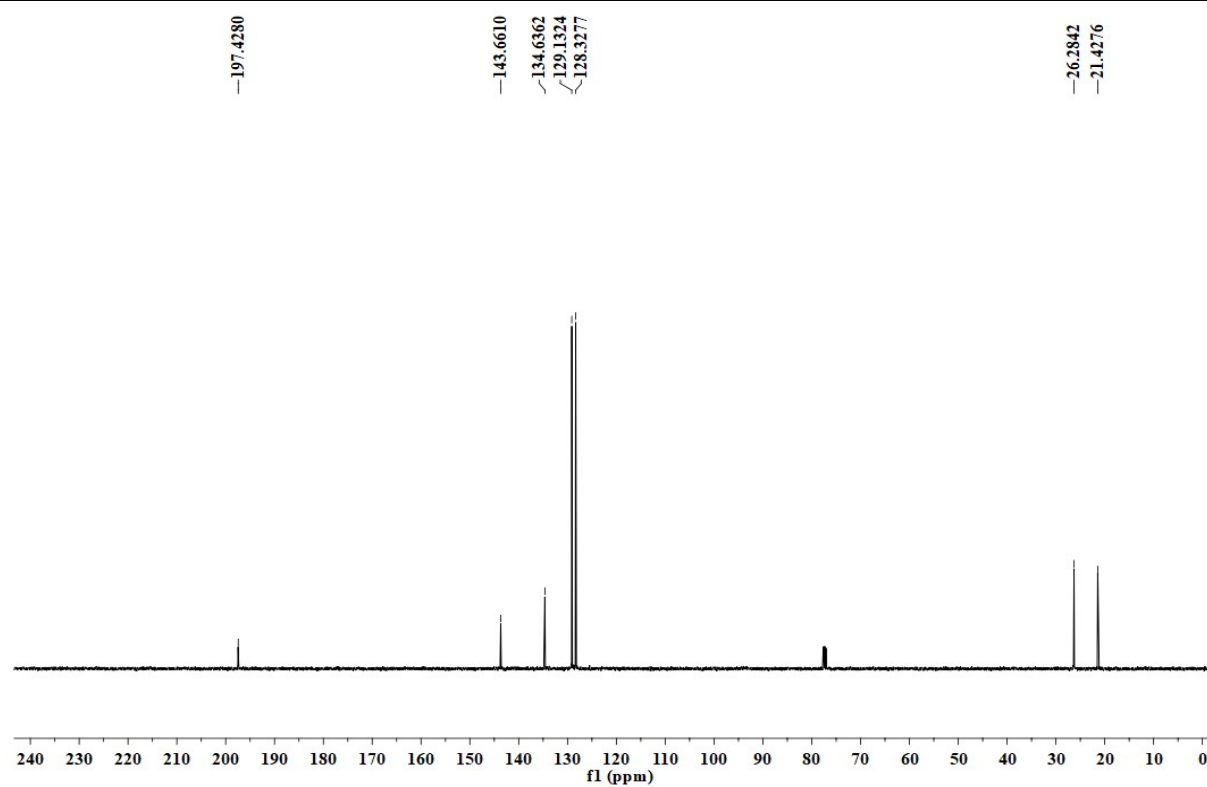


Fig. S29. ^{13}C NMR spectrum of 4 taking CDCl_3 as solvent.

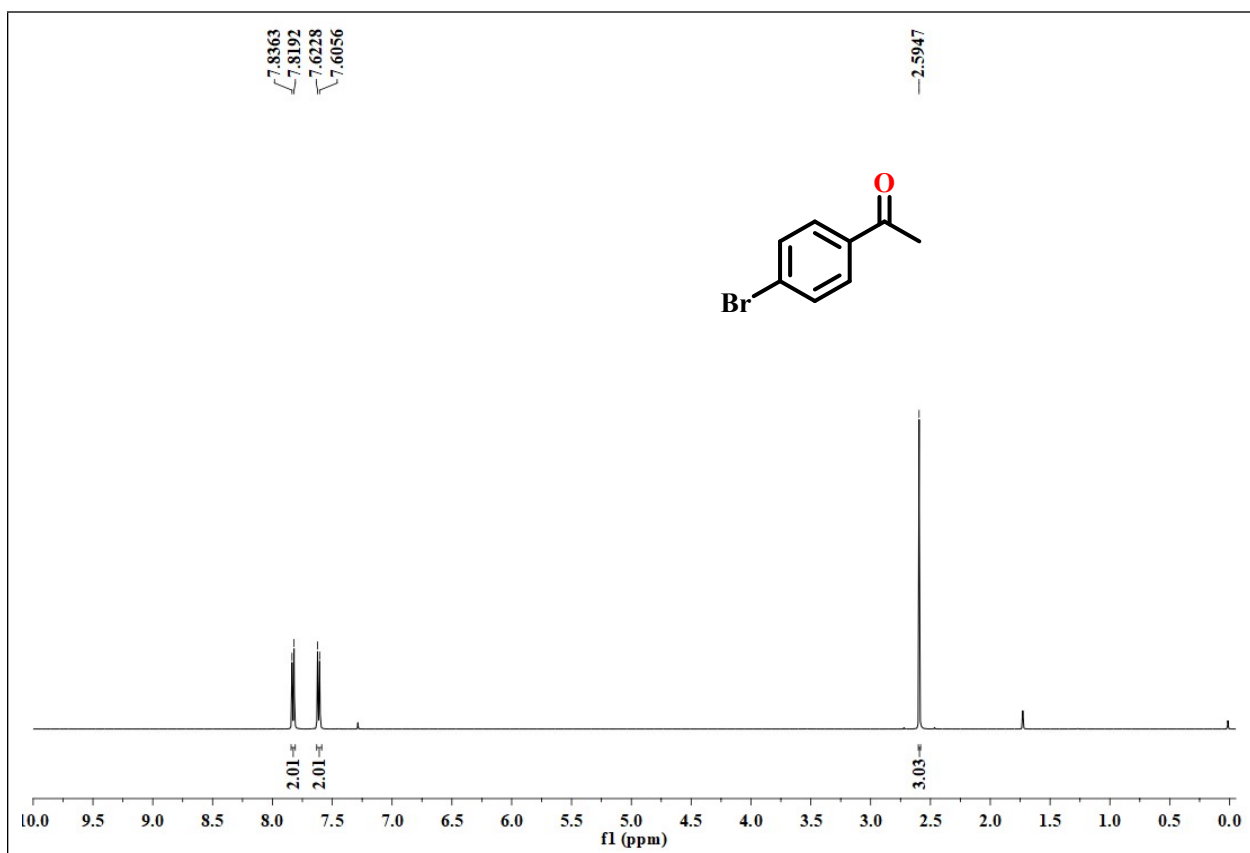


Fig. S30. ¹H NMR spectrum of 5 taking CDCl₃ as solvent.

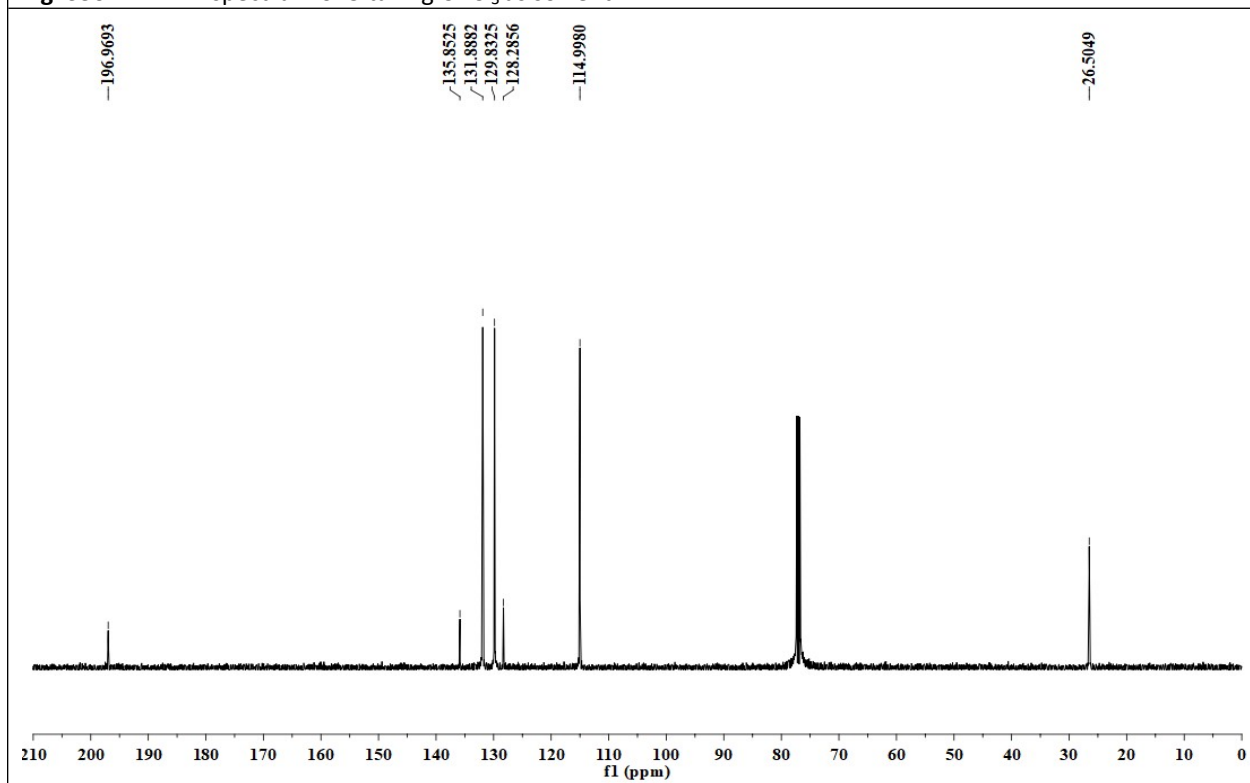


Fig. S31. ¹³C NMR spectrum of 5 taking CDCl₃ as solvent.

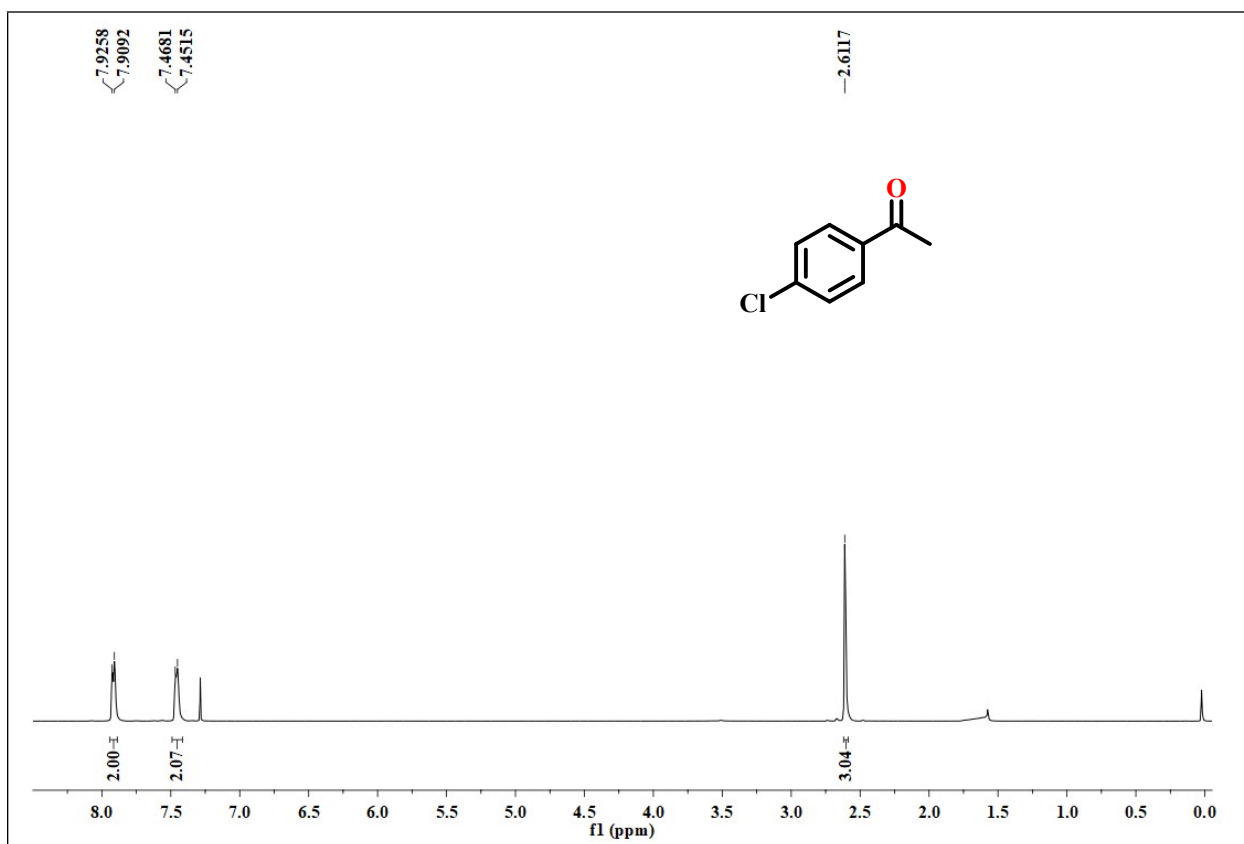


Fig. S32. ¹H NMR spectrum of 6 taking CDCl₃ as solvent.

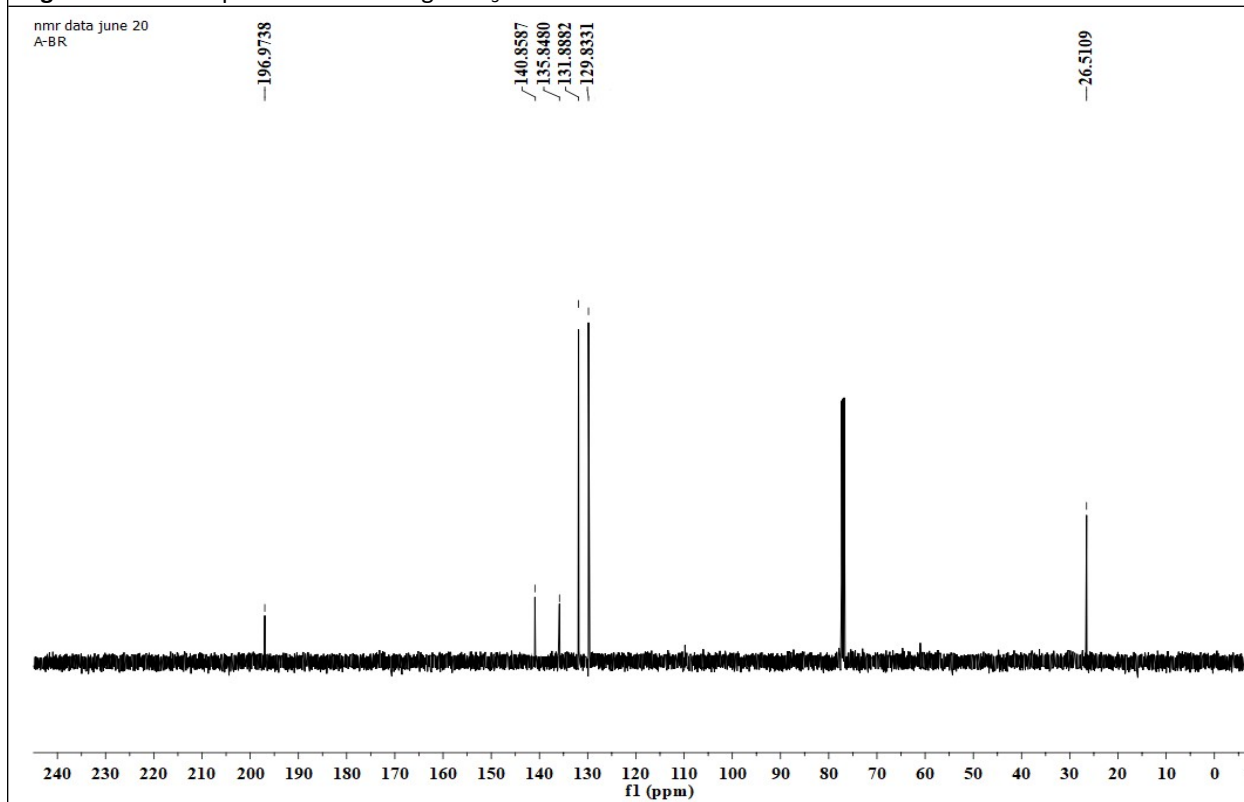


Fig. S33. ¹³C NMR spectrum of 6 taking CDCl₃ as solvent.

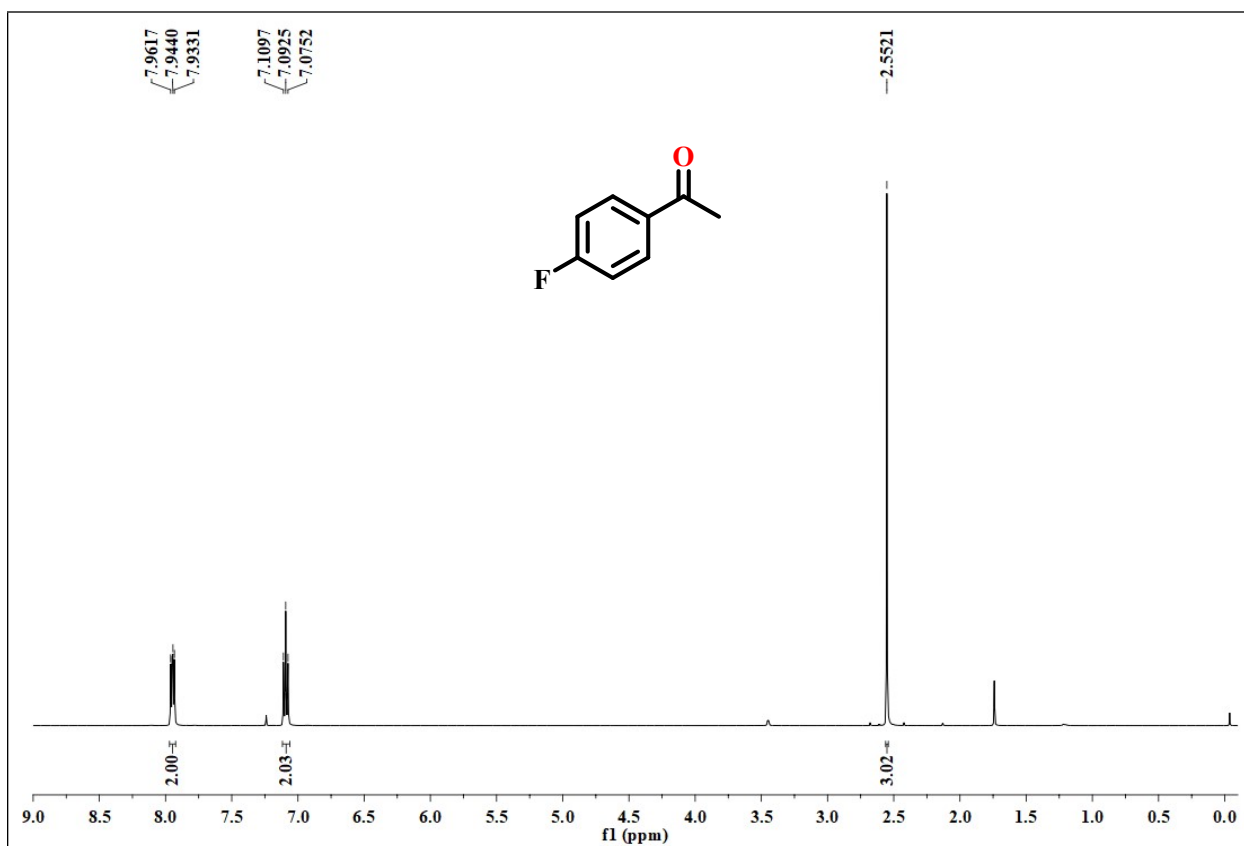


Fig. S34. ¹H NMR spectrum of 7 taking CDCl₃ as solvent.

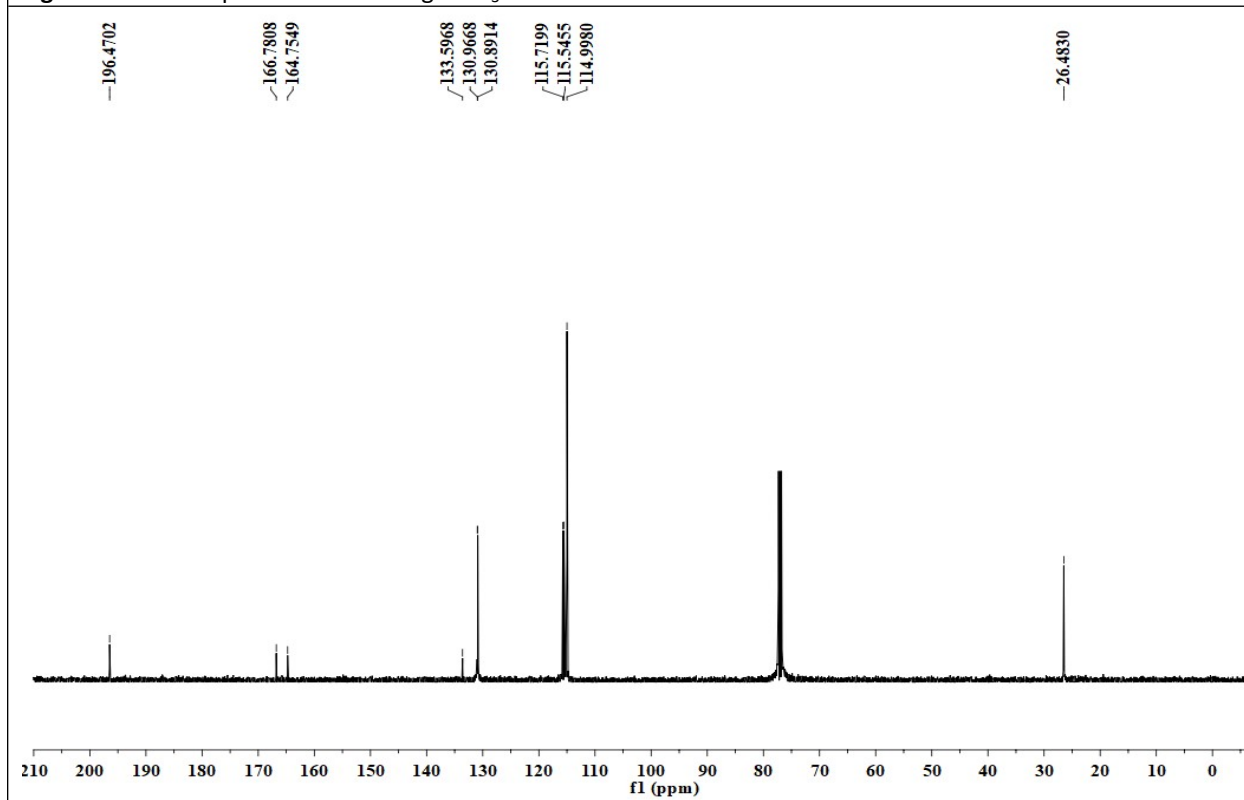


Fig. S35. ¹³C NMR spectrum of 7 taking CDCl₃ as solvent.

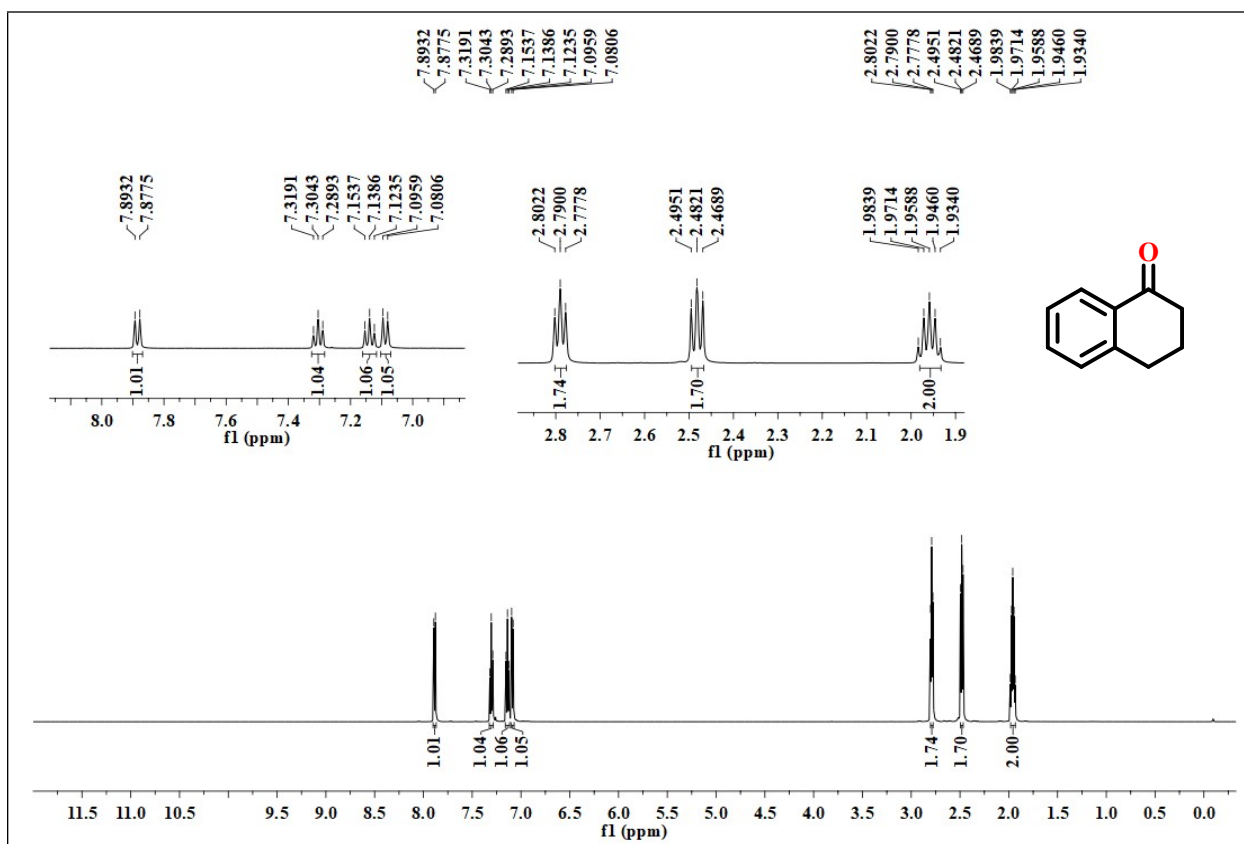


Fig. S36. ¹H NMR spectrum of 8 taking CDCl₃ as solvent.

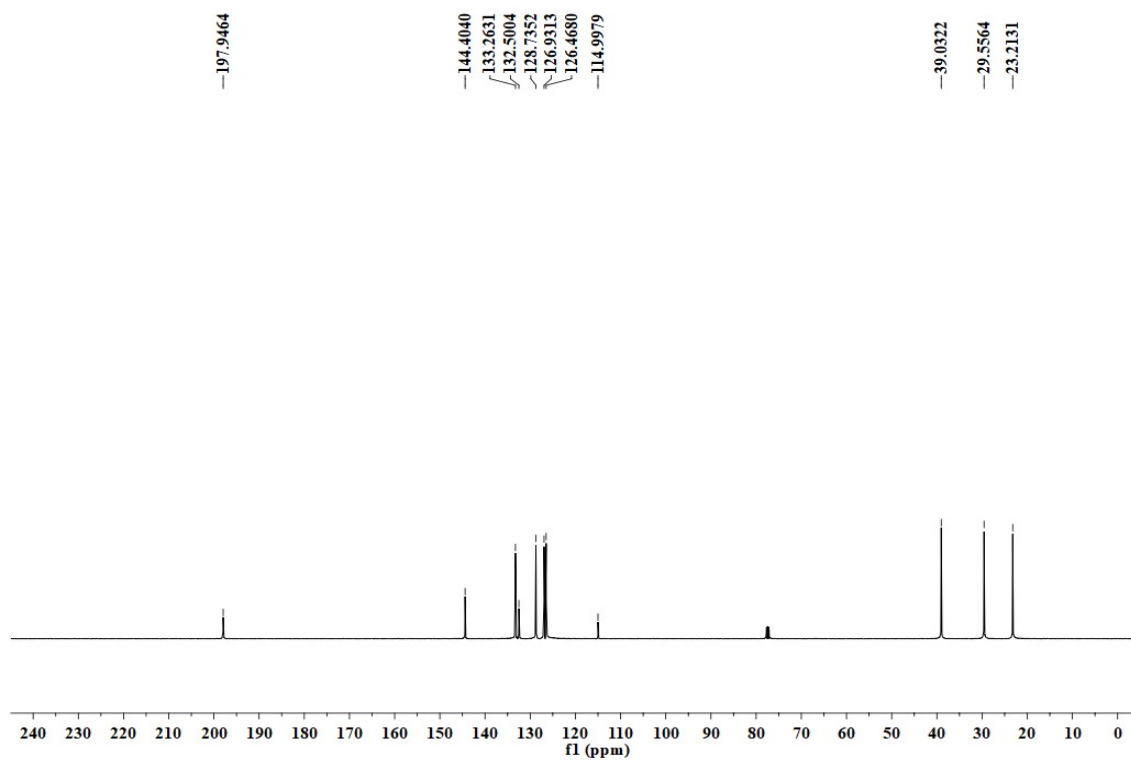


Fig. S37. ¹³C NMR spectrum of 8 taking CDCl₃ as solvent.

Table S11: Data analysis for oxidation of cyclohexane^a

Complex	% Conversion		TON ^b	TOF(h ⁻¹)
	A	B		
Co ₂ (L ¹)(H ₂ O) ₂ Cl ₄ (1)	20	15	5	0.4
Co ₂ (L ²)(H ₂ O) ₂ Cl ₄ (2)	31	18	7	0.6

^aAll reactions were carried out in CH₃CN at 60 °C. Cyclohexane (1 mmol), **Complex** (0.04 mmol), and TBHP (8 mmol).

% Conversion = mmole of product/ mmole of reactant

^bTON = mmol of product/mmol of catalyst loading

^cTOF = TON / time (in hours).

Table S12: Data analysis for oxidation of phenylacetonitrile ^a			
Complex	% Conversion	TON ^b	TOF (h ⁻¹)
Co ₂ (L ¹)(H ₂ O) ₂ Cl ₄ (1)	51	13	1
Co ₂ (L ²)(H ₂ O) ₂ Cl ₄ (2)	48	12	1

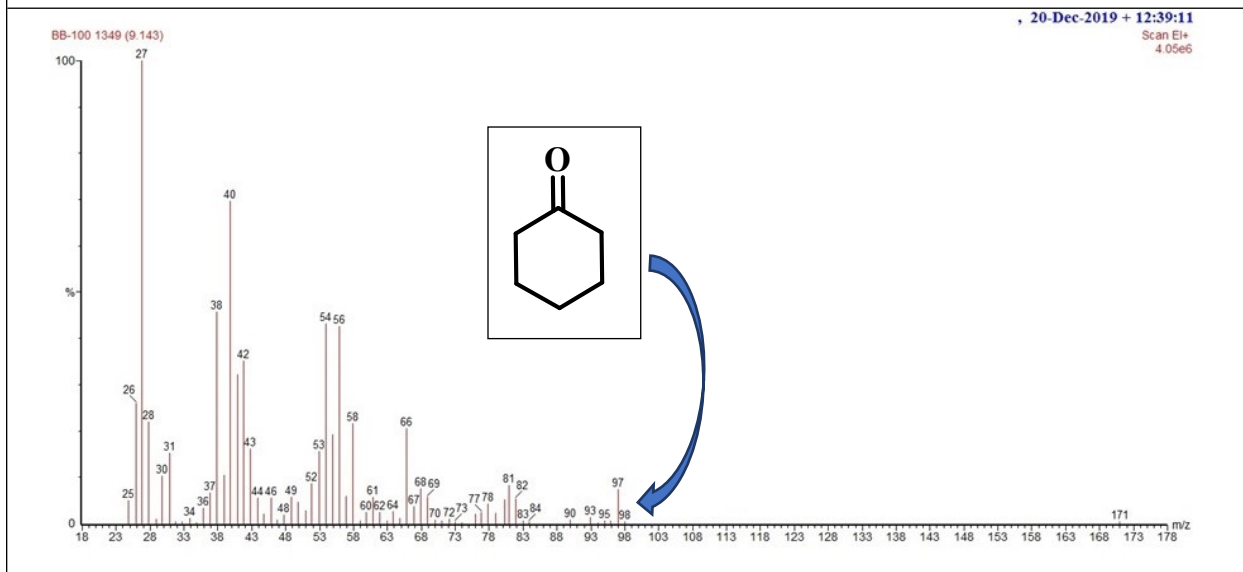
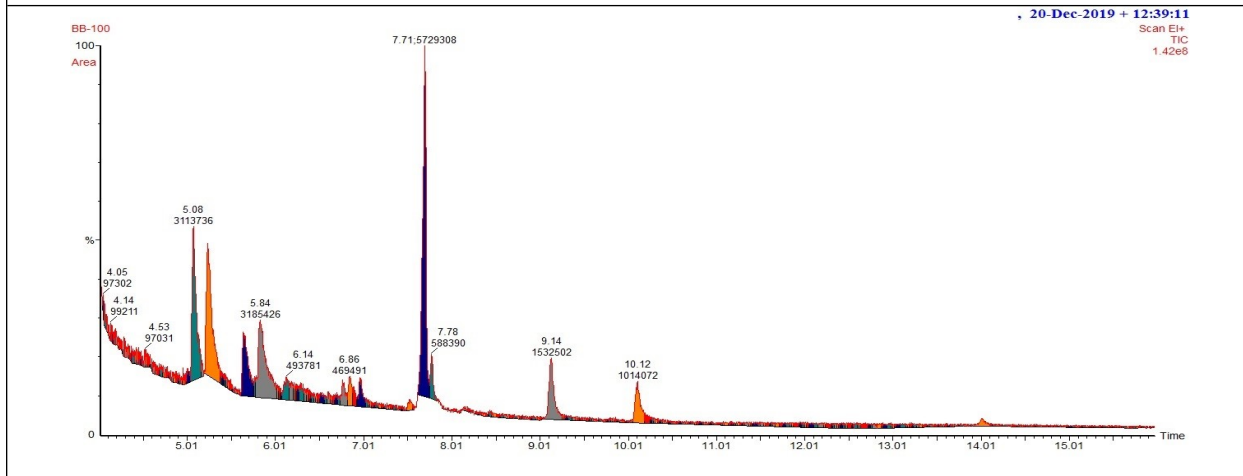
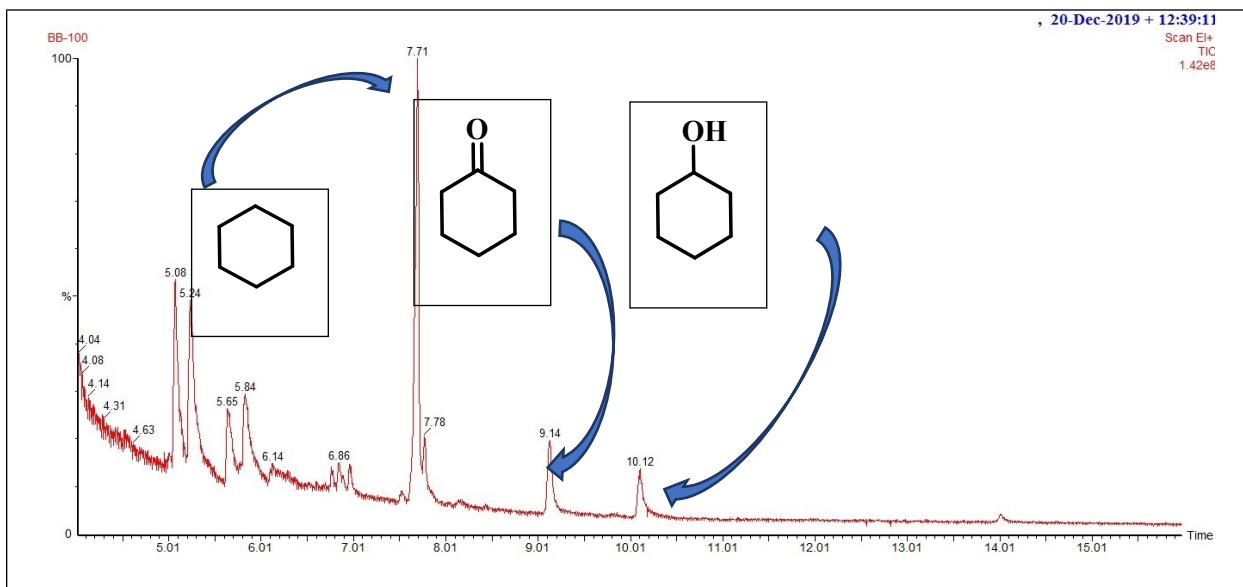
^aAll reactions were carried out in CH₃CN at 60 °C. Phenylacetonitrile (1 mmol), **Complex** (0.04 mmol), and TBHP (8 mmol).
 % Conversion = mmole of product/ mmole of reactant
^bTON = mmol of product/mmol of catalyst loading
^cTOF = TON / time (in hours).

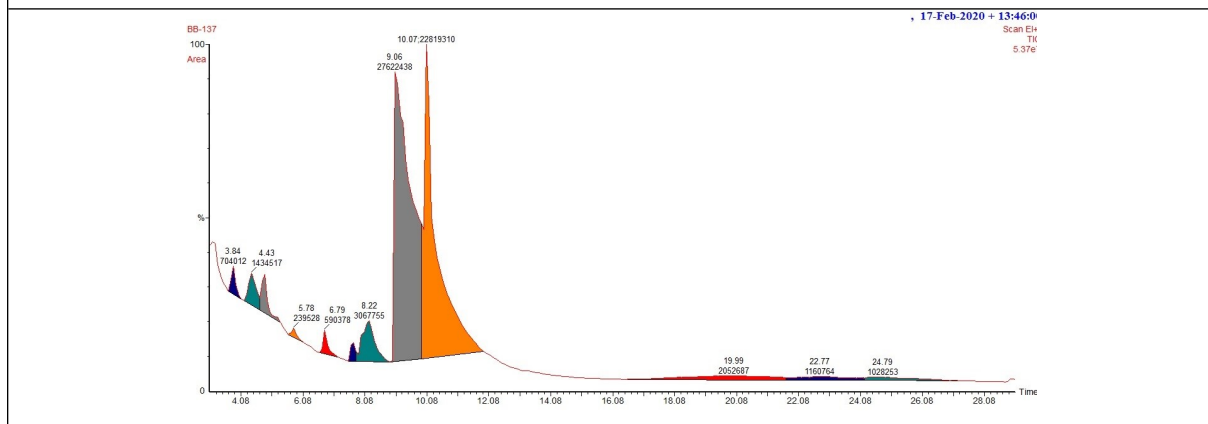
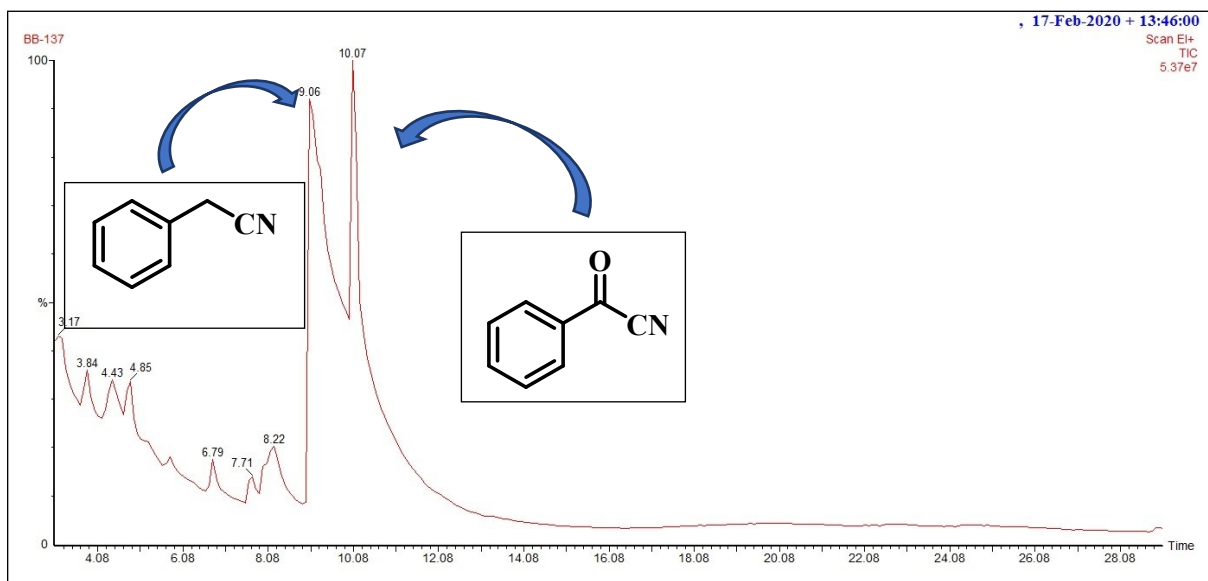
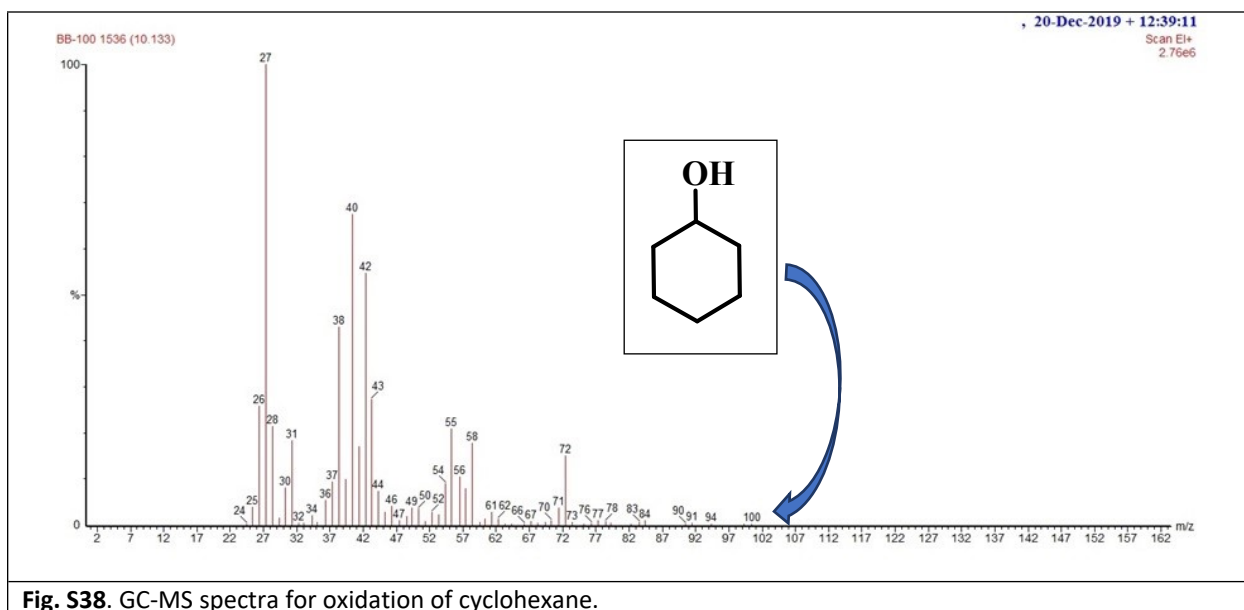
Table S13: Data analysis for oxidation of 9,10-dihydroanthracene ^a			
Complex	% Conversion	TON ^b	TOF (h ⁻¹)
Co ₂ (L ¹)(H ₂ O) ₂ Cl ₄ (1)	59	14	1.3
Co ₂ (L ²)(H ₂ O) ₂ Cl ₄ (2)	52	13	1

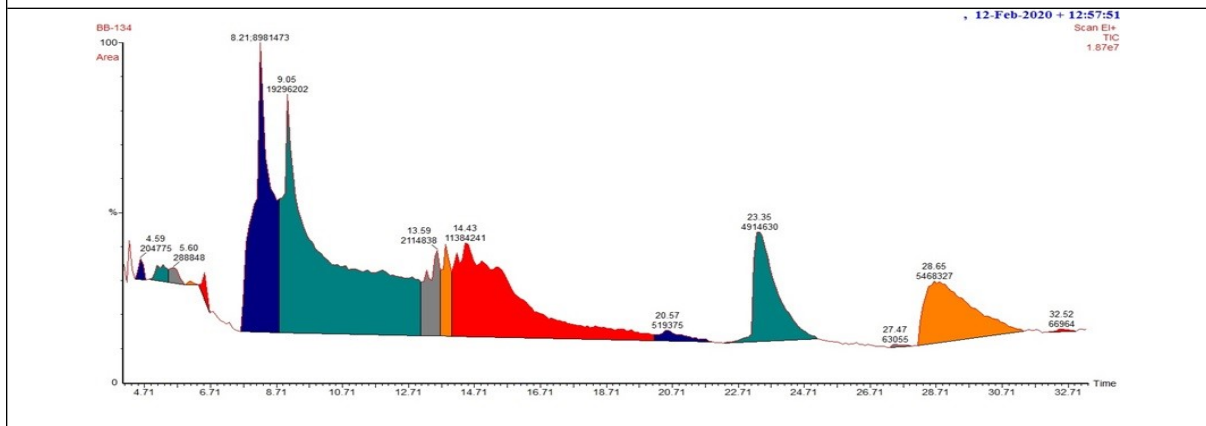
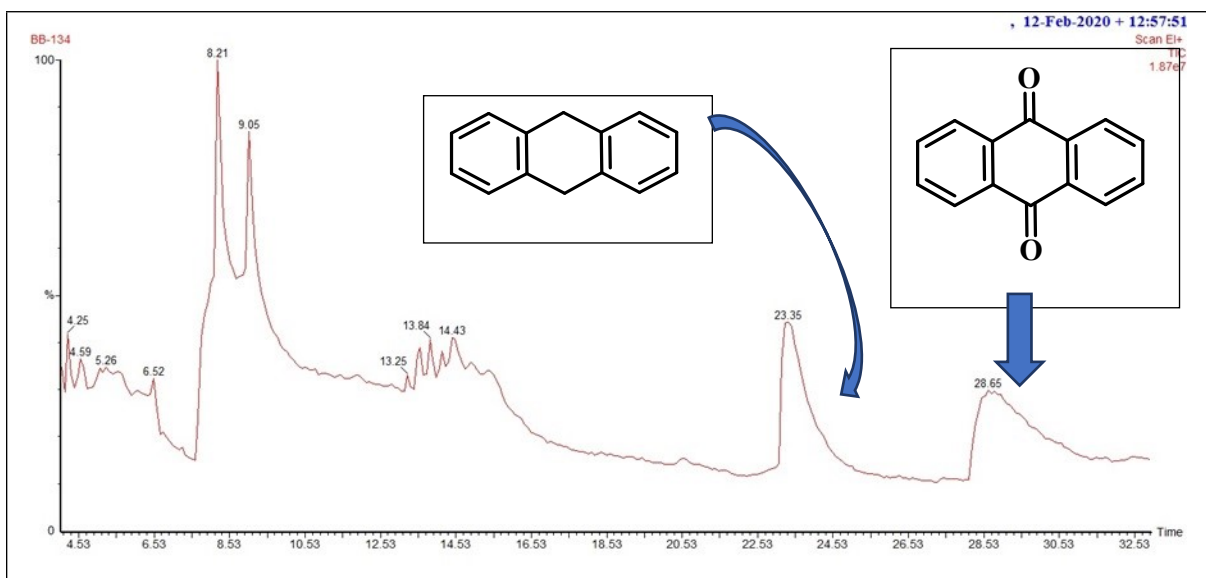
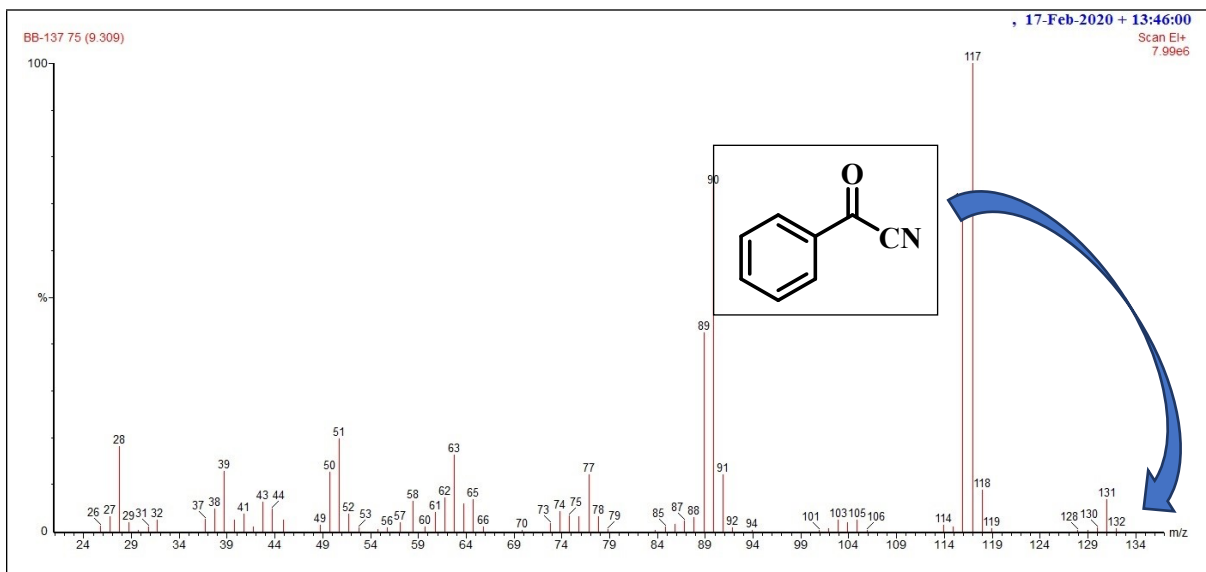
^aAll reactions were carried out in CH₃CN at 60 °C. 9,10-dihydroanthracene (1 mmol), **Complex** (0.04 mmol), and TBHP (8 mmol).
 % Conversion = mmole of product/ mmole of reactant
^bTON = mmol of product/mmol of catalyst loading
^cTOF = TON / time (in hours).

Table S14: Data analysis for oxidation of adamantane ^a				
Complex	% Conversion		TON ^b	TOF (h ⁻¹)
	A	B + C		
Co ₂ (L ¹)(H ₂ O) ₂ Cl ₄	36	15	13	1
Co ₂ (L ²)(H ₂ O) ₂ Cl ₄	28	13	10	0.8

^aAll reactions were carried out in CH₃CN at 60 °C. adamantane (1 mmol), **Complex** (0.04 mmol), and TBHP (8 mmol).
 % Conversion = mmole of product/ mmole of reactant
^bTON = mmol of product/mmol of catalyst loading
^cTOF = TON / time (in hours).







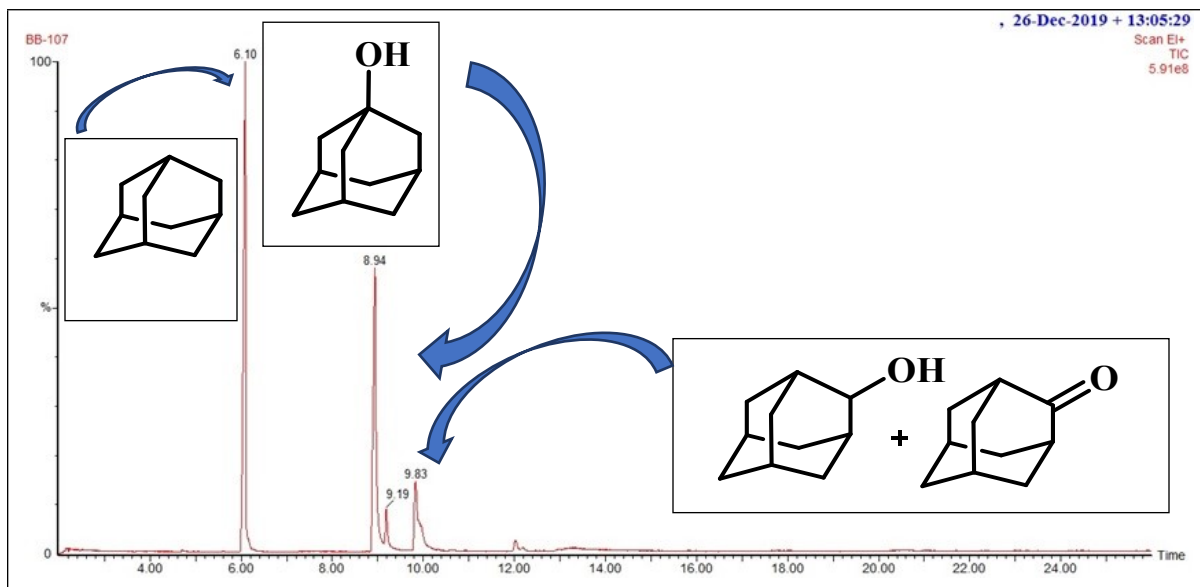
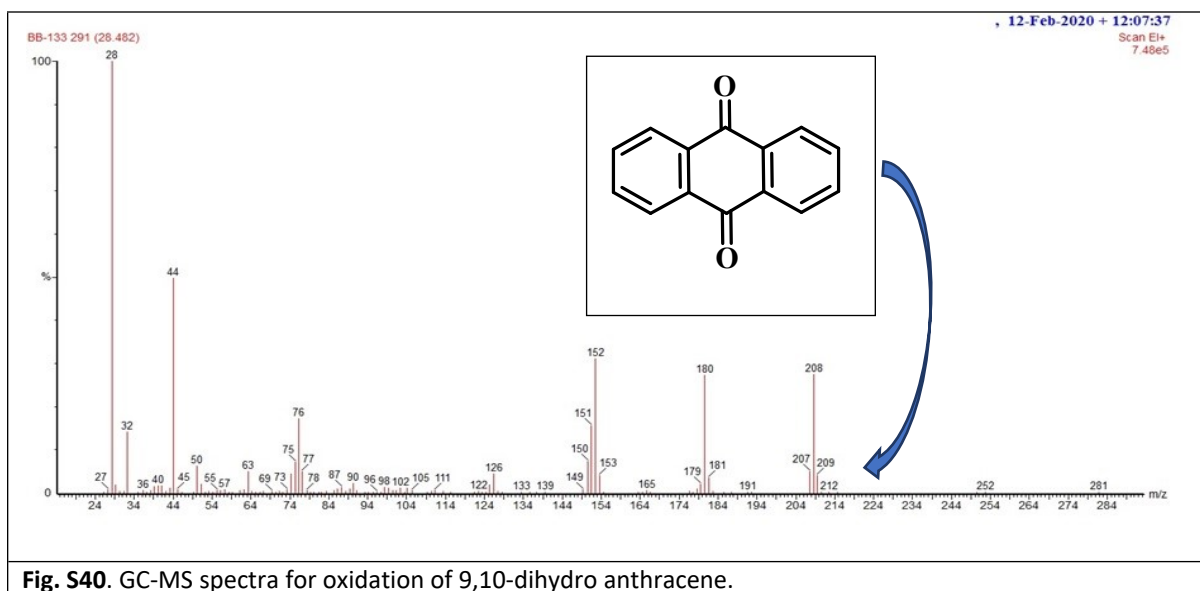


Fig. S42: Packing diagram of complex **1** (projection at c*-axis).

Table S15: Comparative study of literature for the oxidation of different alkanes				
Catalyst	Substrate	Product	% conversion or % Yield	Reference
[Co(bis(imino)pyridine) (OTf) ₂] [Co(bis(amino)pyridine) (OTf) ₂]	Cyclohexane	Cyclohexanol Cyclohexanone	33	¹³
[Cp*Co(bipy)Cl]PF ₆ [Cp*Co(bipy)I]PF ₆ [Cp*Co(phen)I]PF ₆	Cyclohexane	Cyclohexanol	24	¹⁵
[Co([PhB(Melm) ₃])(acac)(MelmH)] ⁺ [Co([PhB(Melm) ₃]) ₂] ⁺	Cyclohexane	Cyclohexanol Cyclohexanone	29	¹⁶
Complex 1	Cyclohexane	Cyclohexanol Cyclohexanone	35	This work
Complex 2	Cyclohexane	Cyclohexanol Cyclohexanone	39	This work
[Co{C ₆ H ₄ C(NH ₂)NC(ONCMe ₂) ₂ } ₂] ²⁺	Adamantane	1-adamantanol 2-adamantanol 2-adamantanone	66	
Complex 1	Adamantane	1-adamantanol 2-adamantanol 2-adamantanone	51	This work

Complex 2	Adamantane	1-adamantanol 2-adamantanol 2-adamantanone	41	This work
Cobalt complex supported with MCM Nano particle.	Diphenyl methane	Benzophenone	29	¹⁰
[Co(tptz)Cl ₂].2H ₂ O	Diphenyl methane	Benzophenone	64	⁹
Complex 1	Diphenyl methane	Benzophenone	72	This work
Complex 2	Diphenyl methane	Benzophenone	35	This work
[Co(tptz)Cl ₂].2H ₂ O	Fluorene	Fluorenone	99	⁹
Complex 1	Fluorene	Fluorenone	94	This work
Complex 2	Fluorene	Fluorenone	91	This work
	1,2,3,4-tetrahydronaphthalene	3,4-dihydronaphthalen-1(2H)-one	52	¹⁴
Complex 1	1,2,3,4-tetrahydronaphthalene	3,4-dihydronaphthalen-1(2H)-one	80	This work
Complex 2	1,2,3,4-tetrahydronaphthalene	3,4-dihydronaphthalen-1(2H)-one	78	This work
Silica supported cobalt complexes	Ethylbenzene	Acetophenone	69	¹²
Complex 1	Ethylbenzene	Acetophenone	79	This work
Complex 2	Ethylbenzene	Acetophenone	75	This work
Silica supported cobalt complexes	1-bromo-4-ethylbenzene	1-(4-bromophenyl)ethan-1-one	75	¹²
Complex 1	1-bromo-4-ethylbenzene	1-(4-bromophenyl)ethan-1-one	82	This work
Complex 2	1-bromo-4-ethylbenzene	1-(4-bromophenyl)ethan-1-one	78	This work
Silica supported cobalt complexes	1-chloro-4-ethylbenzene	1-(4-chlorophenyl)ethan-1-one	76	¹²
Complex 1	1-chloro-4-ethylbenzene	1-(4-chlorophenyl)ethan-1-one	79	This work
Complex 2	1-chloro-4-ethylbenzene	1-(4-chlorophenyl)ethan-1-one	73	This work

References

- 1 K. Ghosh, V. Mohan, P. Kumar, S. W. Ng and E. R. T. Tiekink, *Inorg. Chim. Acta*, 2014, **416**, 76–84.
- 2 Y. Chen, R. Chen, C. Qian, X. Dong and J. Sun, *Organometallics*, 2003, **22**, 4312–4321.
- 3 S. H. Ahn, S. Il Choi, M. J. Jung, S. Nayab and H. Lee, *J. Mol. Struct.*, 2016, **1113**, 24–31.

- 4 C. Moyses Araujo, M. D. Doherty, S. J. Konezny, O. R. Luca, A. Usyatinsky, H. Grade, E. Lobkovsky, G. L. Soloveichik, R. H. Crabtree and V. S. Batista, *Dalton Trans.*, 2012, **41**, 3562–3573.
- 5 K. Ghosh, V. Mohan, P. Kumar and U. P. Singh, *Polyhedron*, 2013, **49**, 167–176.
- 6 S. H. Ahn, S. Il Choi, M. J. Jung, S. Nayab and H. Lee, *J. Mol. Struct.*, 2016, **1113**, 24–31.
- 7 A. Abu Shamma, H. Abu Ali and S. Kamel, *Appl. Organomet. Chem.*, 2018, **32**, 1–12.
- 8 J. Drzeżdżon, J. Malinowski, A. Sikorski, B. Gawdzik, P. Rybiński, L. Chmurzyński and D. Jacewicz, *Polyhedron*, 2020, **175**, 1–10.
- 9 Z. Azarkamanzad, F. Farzaneh, M. Maghami and J. Simpson, *New J. Chem.*, 2019, **43**, 12020–12031.
- 10 S. S. Bhoware, K. R. Kamble and A. P. Singh, *Catal. Letters*, 2009, **133**, 106–111.
- 11 O. V. Nesterova, M. N. Kopylovich and D. S. Nesterov, *RSC Adv.*, 2016, **6**, 93756–93767.
- 12 F. Rajabi, R. Luque, J. H. Clark, B. Karimi and D. J. MacQuarrie, *Catal. Commun.*, 2011, **12**, 510–513.
- 13 G. J. P. Britovsek, J. England, S. K. Spitzmesser, A. J. P. White and D. J. Williams, *Dalton Trans.*, 2005, 945–955.
- 14 A. N. Kharat, B. T. Jahromi and A. Bakhoda, *Transit. Met. Chem.*, 2012, **37**, 63–69.
- 15 G. B. Shul'pin, D. A. Loginov, L. S. Shul'pina, N. S. Ikonnikov, V. O. Idrisov, M. M. Vinogradov, S. N. Osipov, Y. V. Nelyubina and P. M. Tyubaeva, *Molecules*, 2016, **21**, 1–17.
- 16 T. Nishiura, A. Takabatake, M. Okutsu, J. Nakazawa and S. Hikichi, *Dalton Trans.*, 2019, **48**, 2564–2568.