Electronic Supplementary Material (ESI) for Chemical Communications
This journal is © The Royal Society of Chemistry 2014

Electronic Supplementary Information

A highly selective fluorescent probe for cadmium ion in aqueous solution and living cells

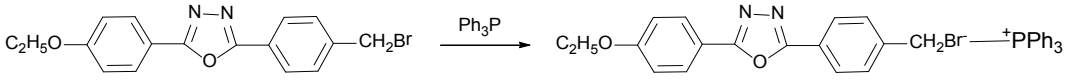
Qiaoling Liu,[a,b] Lixia Feng,[a,b] Caixia Yuan,[a] Lin Zhang,[a] Shaomin Shuang,[a] Chuan Dong,*[a] Qin Hu[c] and Martin M. F. Choi*[c]

[a]*Institute of Environmental Science, and School of Chemistry and Chemical Engineering, Shanxi University, Taiyuan 030006, P. R. China. Fax: +86-351-7018613; Tel: +86-351-7018613; E-mail: dc@sxu.edu.cn*

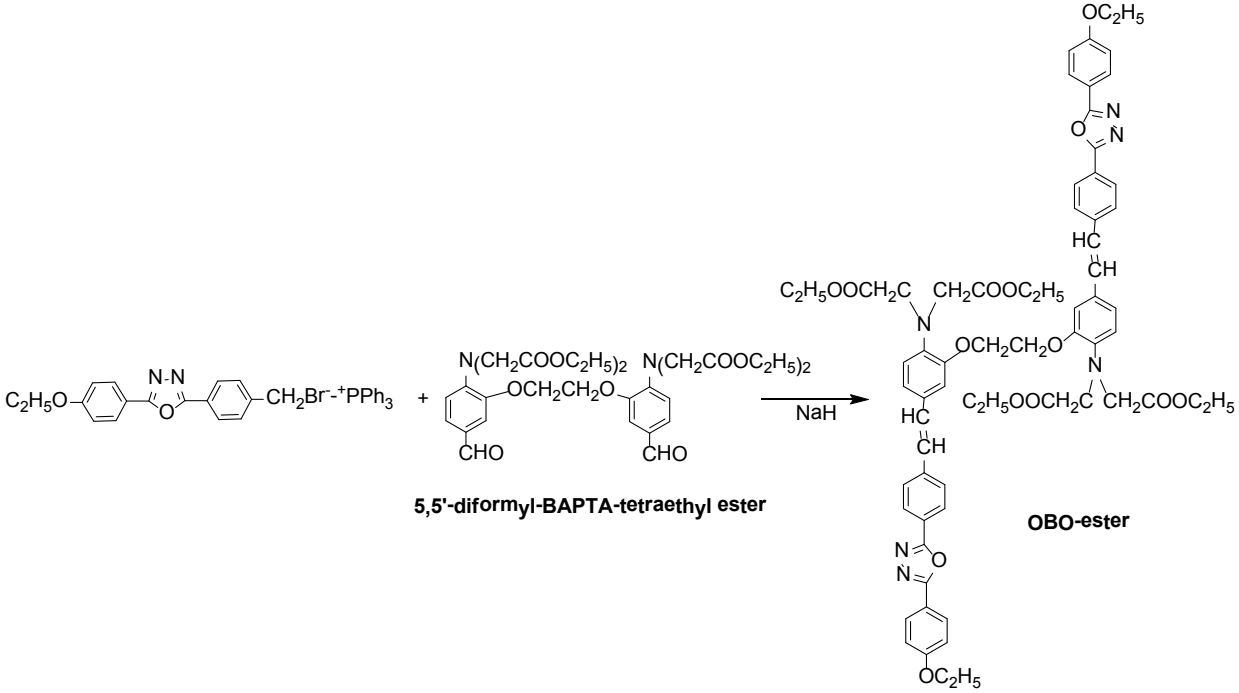
[b]*Department of Chemistry, Taiyuan Normal University, Taiyuan 030031, P. R. China.*

[c]*Department of Chemistry, Hong Kong Baptist University, 224 Waterloo Road, Kowloon Tong, Hong Kong SAR, P. R. China. Fax: +852-34117348; Tel: +852-34117839; E-mail: mfchoi@hkbu.edu.hk*

Synthesis of OBO-ester



2-[(4-bromomethyl)phenyl]-5-(4-ethoxyphenyl)-1,3,4-oxadiazole



5,5'-diformyl-BAPTA-tetraethyl ester

OBO-ester

(2-[(4-bromomethyl)phenyl]-5-(4-ethoxyphenyl)-1,3,4-oxadiazole) (3.40 g, 9.46 mmol) and triphenylphosphine (2.57 g, 9.80 mmol) were added to 45 mL dry benzene and the mixture was heated under reflux for 4 h. After cooling to room temperature, the reaction mixture was filtered to obtain the white solid phosphorane ylide and dried in vacuum (5.75 g, 9.26 mmol). Sodium hydride (0.32 g, 8.00 mmol) was put into 8 mL of petroleum ether under N_2 atmosphere and stirred for 20 min. The petroleum ether was discarded and replaced with 30 mL dried CH_2Cl_2. Phosphorane ylide (4.13g, 6.65 mmol) was added and stirred at room temperature for 1 h. 5,5'-Diformyl-BAPTA-tetraethyl ester was synthesized from BAPTA-tetraethyl ester based on the literature methods.[1,2] 5,5'-Diformyl-BAPTA-tetraethyl ester (2.1 g, 3.26 mmol) was loaded into the mixture and stirred at room temperature for 6 h. The mixture was concentrated and purified by

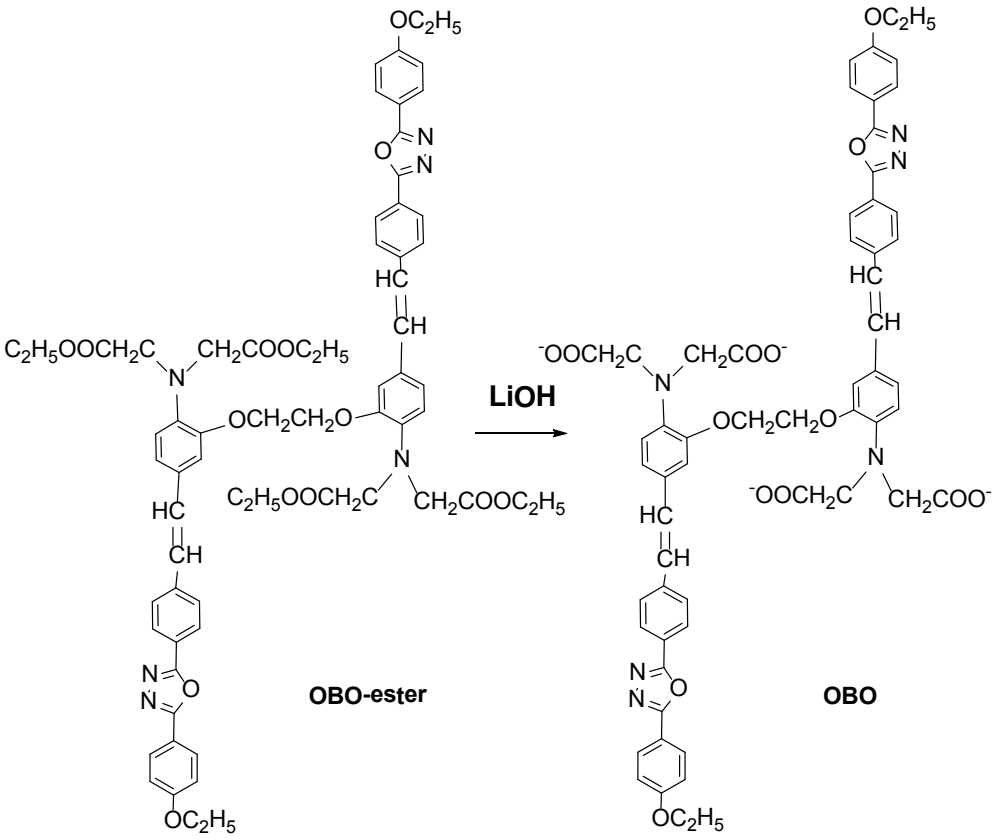
column chromatography using silica gel as the stationary phase and *n*-hexane/ethyl acetate (1:1) as the eluent to obtain the greenish yellow solid OBO-ester (2.1 g, 55.5 % yield). Melting point: 60–62 °C. The ^{1}H NMR (600 MHz, $CDCl_3$) data are δ 8.08 (d, Ar-H, 4H), 7.76 (d, Ar-H, 4H), 7.56 (d, Ar-H, 2H), 7.53 (d, Ar-H, 2H), 7.40 (d, Ar-H, 2H), 7.29 (d, Ar-H, 2H), 7.05 (d, Ar-H, 4H), 6.87 (s, Ar-H, 2H), 6.95 (d, -CH=CH-, 4H), 4.35 (s, $-CH_2-CH_2-$, 4H), 4.31 (s, $-CH_2-$, 8H), 4.13 (q, $-CH_2-$.8H), 4.06(q, $-CH_2-$.4H), 1.32 (s, CH_3-, 6H), and 1.29 (t, CH_3-, 12H). The ^{13}C NMR (600 MHz, $CDCl_3$) data are δ 165, 160, 144, 142, 137, 128, 127, 125, 121, 116, 114, 110, 69, 65, 61, 14.7, and 14.0. MALDI-TOF MS: *m*/*z*: calculated for $C_{66}H_{68}N_6O_{14}^{+}$: 1168.4794; found: 1191.6904 ($M+Na^{+}$). Elemental analysis calculated for $C_{66}H_{68}N_6O_{14}$: C 67.79, H 5.86, N 7.19, and O 19.16 %; found: C 67.81, H 5.85, N 7.21, and O 19.17 %.

References

1 X. Z. Guo, X. M. Wang, Y. K. Du, N. P. Hua, M. Shen, W. L. Jiang and P. Yang, *Chin. Chem. Lett.,* 2005, **16**, 597-600.
2 G. Grynkiewicz, M. Poenie and R. Y. Tsien, *J. Biol. Chem.*,1985, **260,** 3440-3450.

Synthesis of OBO

OBO was obtained by hydrolysing OBO-ester in 0.50 M LiOH solution in an ice bath for 3 h. After hydrolysis, the pH was adjusted to 2–3 by dropwise addition of 1.0 M HCl with stirring. Yellow precipitate was collected by filtration and washed with 3 mL ice-water three times. Then the precipitate was put into 4 equivalents of LiOH solution again and stirred at 0 °C to gain the Li^{+} OBO salt. Finally, the purified Li^{+} OBO product was dried in vacuum and kept at -18 °C until further use.



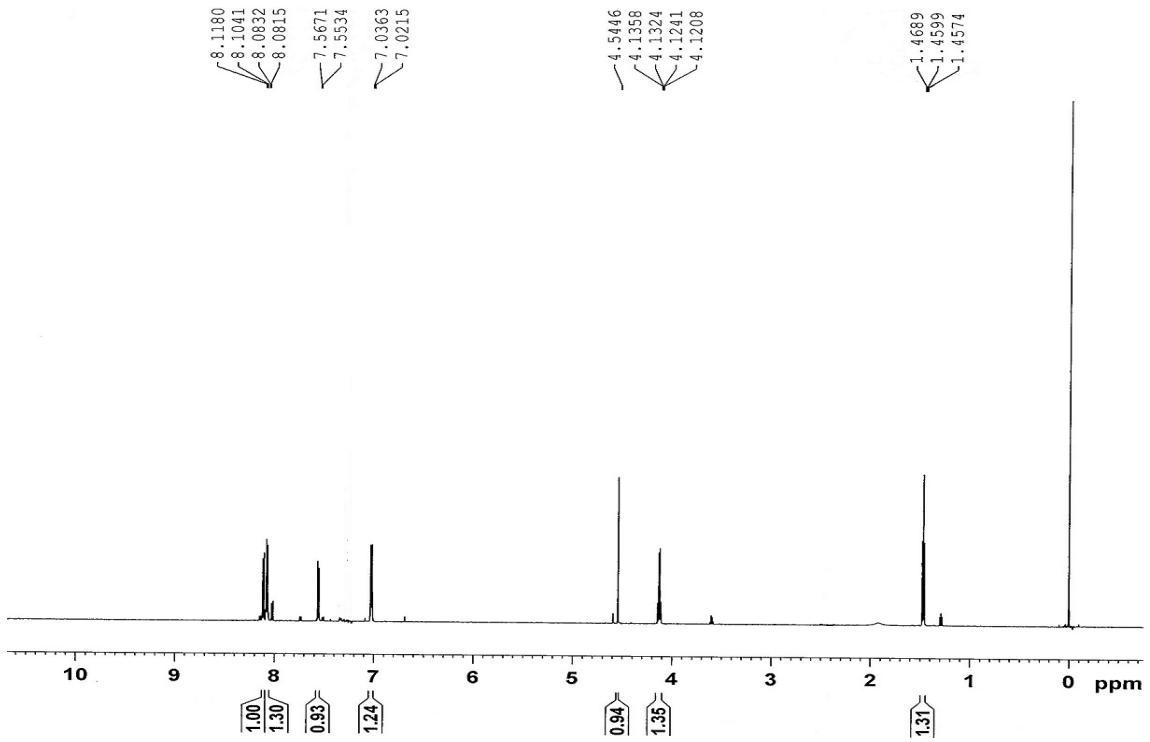


Figure S1. ^{1}H NMR spectrum of 2-[(4-bromomethyl)phenyl]-5-(4-ethoxy phenyl)-1,3,4-oxadiazole in $CDCl_3$.

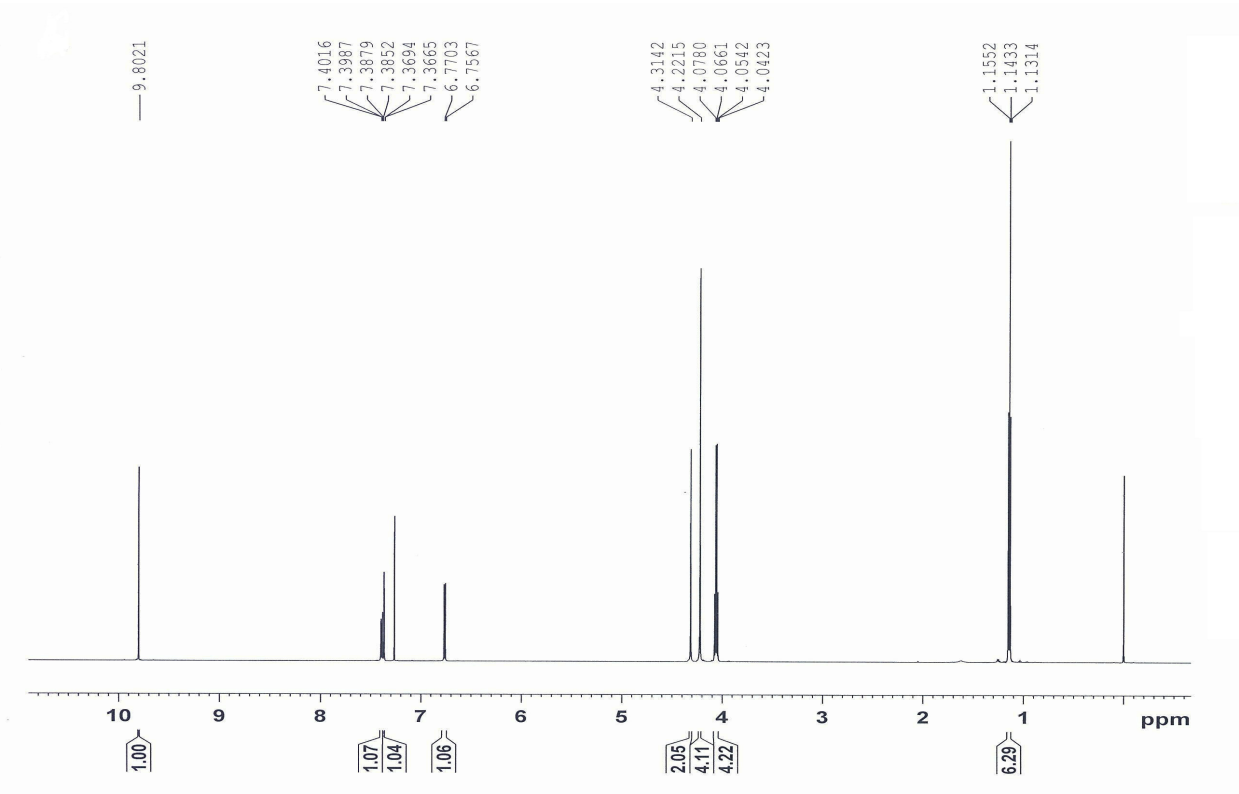


Figure S2. ^{1}H NMR spectrum of 5,5'-diformyl-BAPTA-tetraethyl ester in $CDCl_3$.

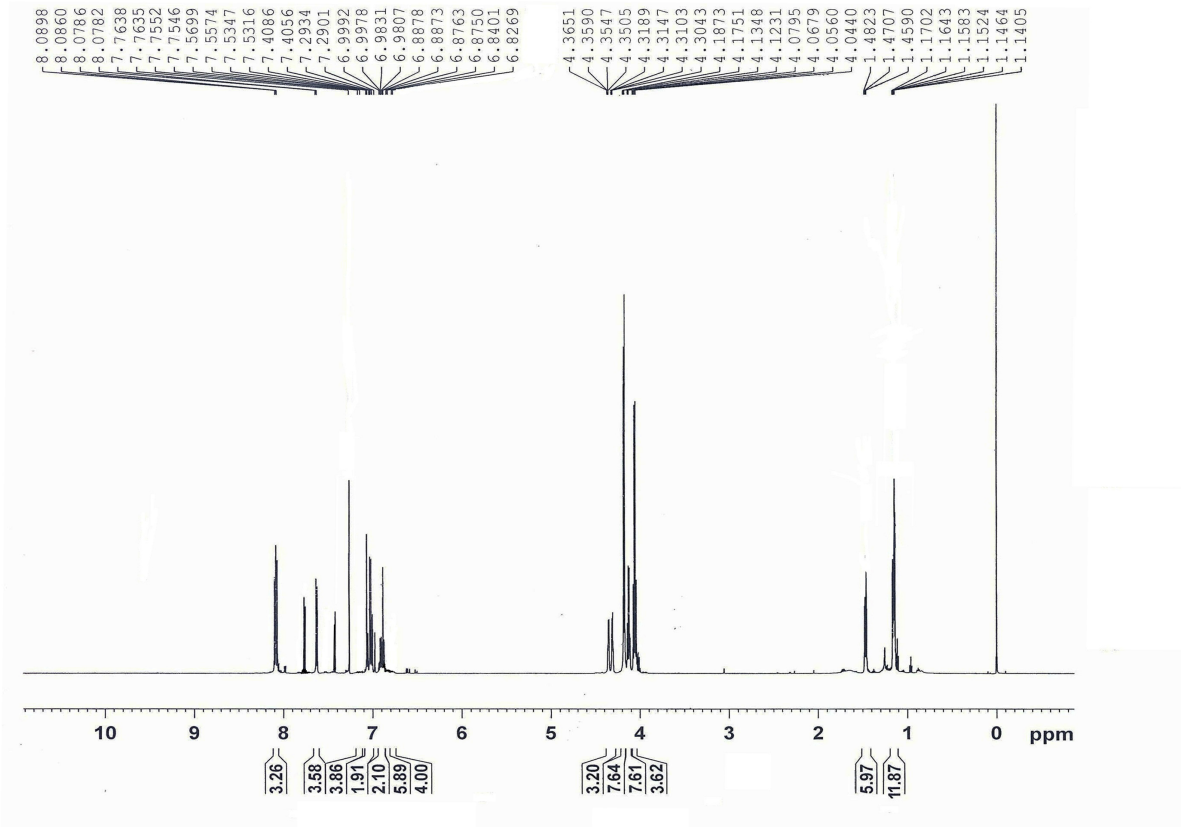


Figure S3. ^{1}H NMR spectrum of OBO-ester in $CDCl_3$.

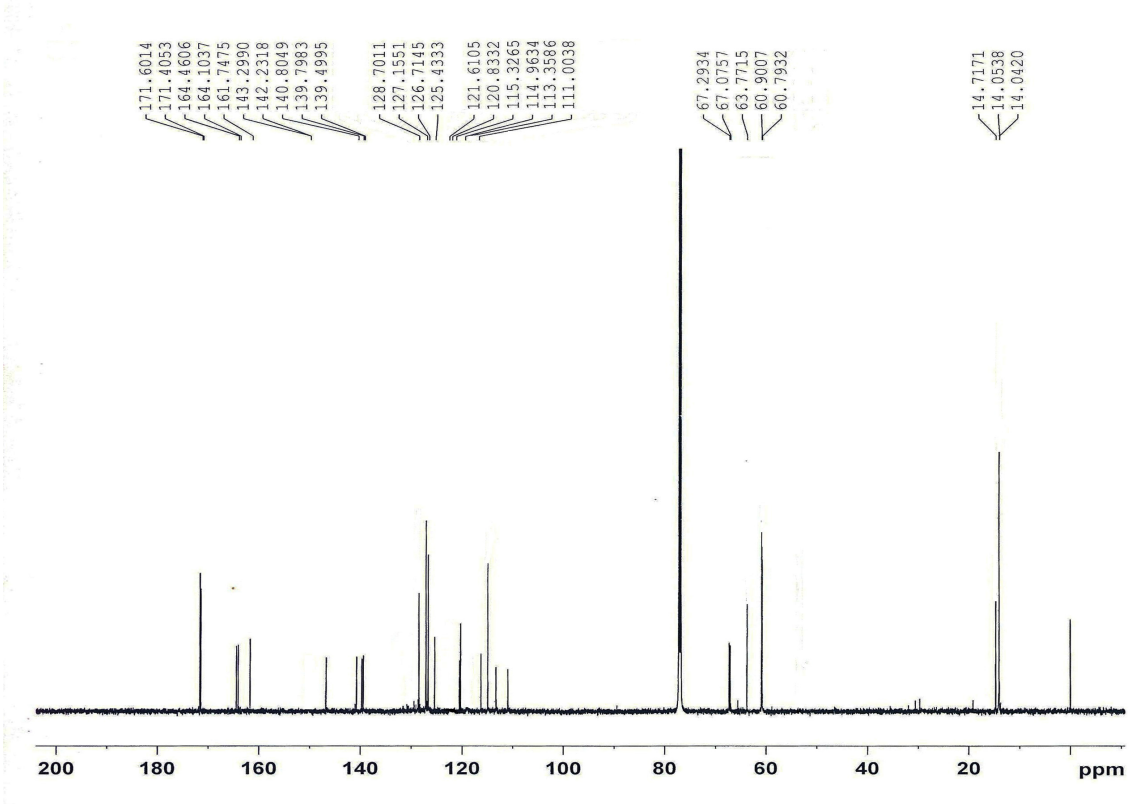


Figure S4. ^{13}C NMR spectrum of OBO-ester in $CDCl_3$.

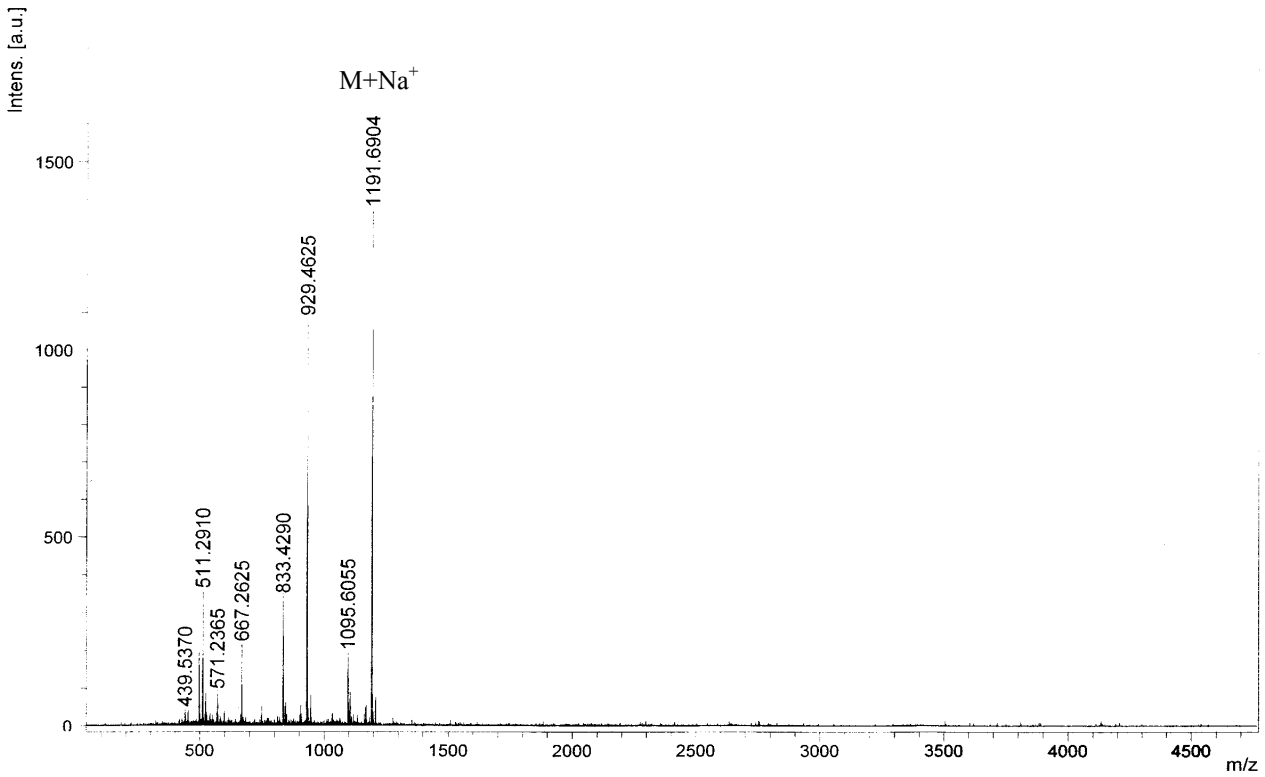


Figure S5. MALDI-TOF MS of OBO-ester.

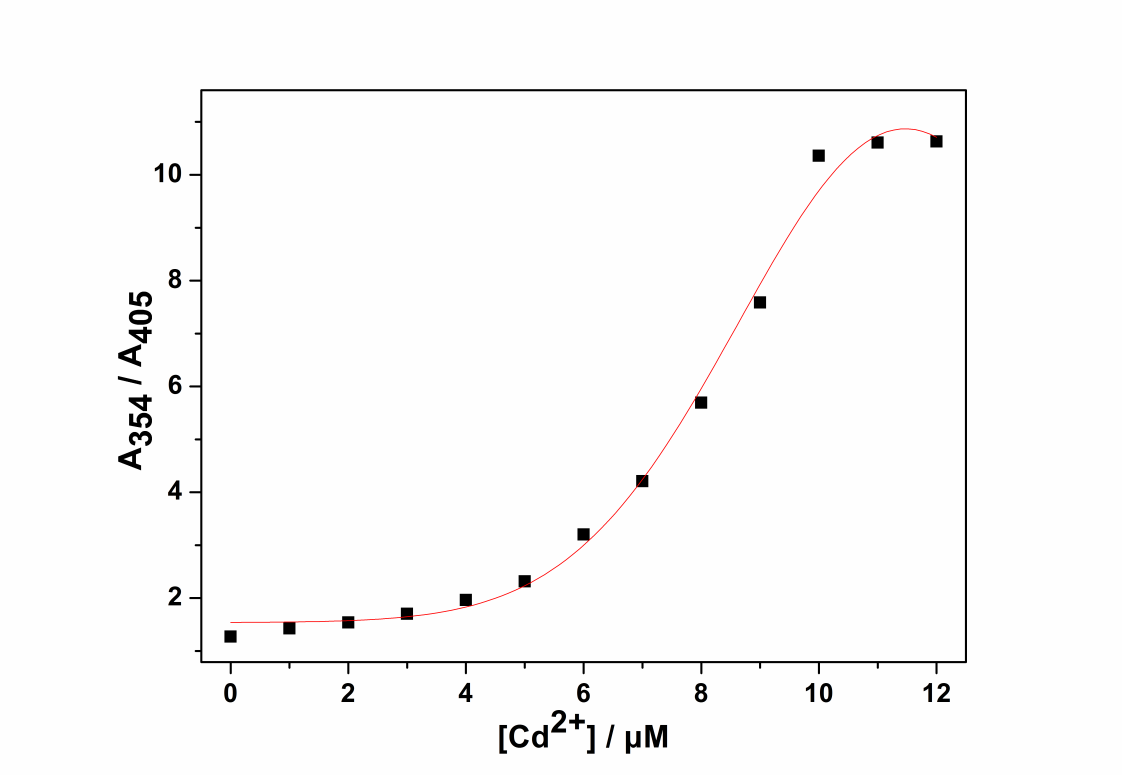


Figure S6. Ratiometric calibration curve A_{354}/A_{405} as a function of Cd^{2+} concentration. A_{354}/A_{405} is the ratio of absorbances at 354 and 405 nm.

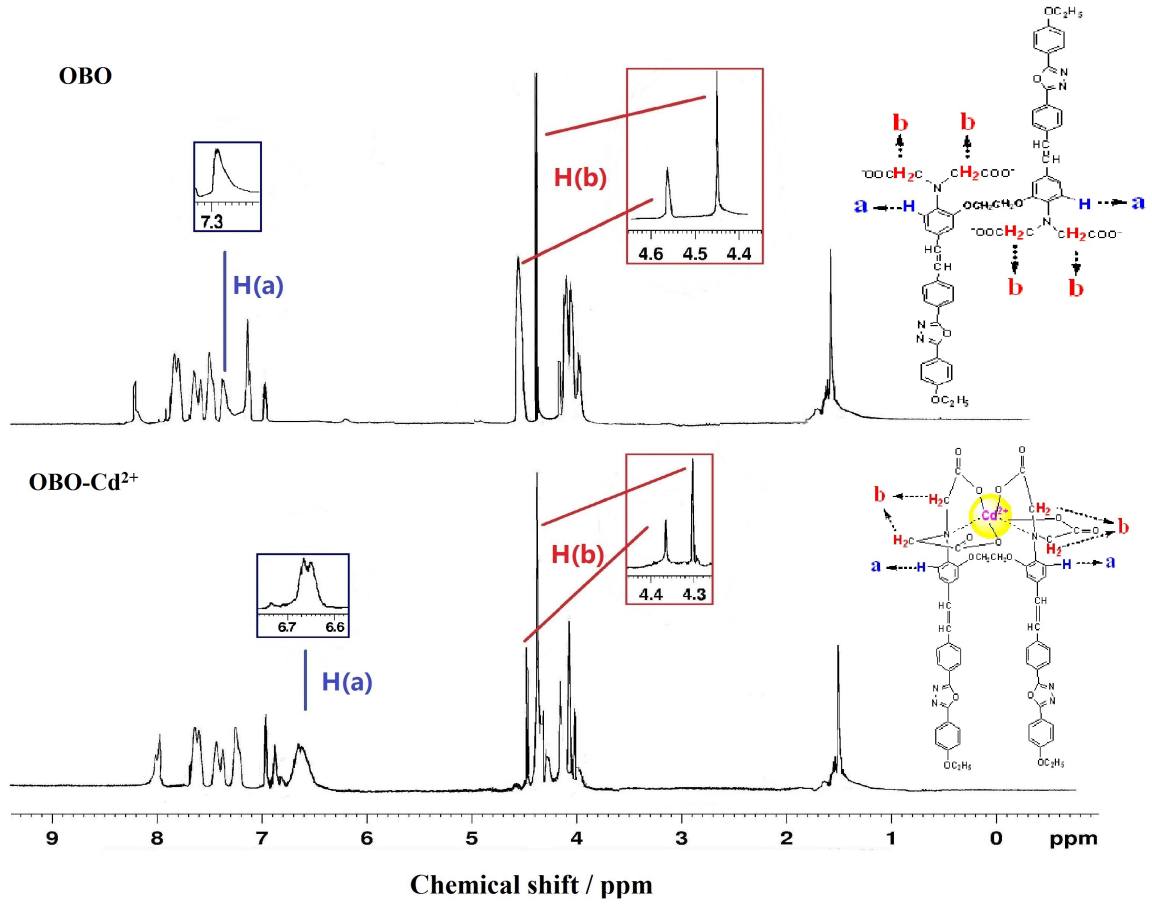


Figure S7. ^{1}H NMR spectra of OBO in the presence or absence of Cd^{2+} in D_2O.

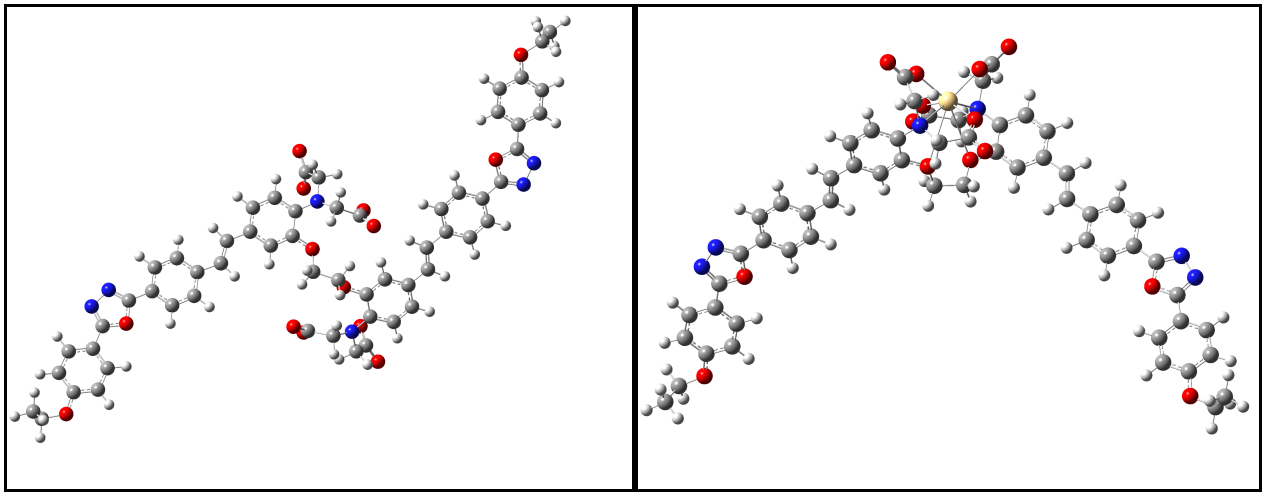


Figure S8. The optimal geometries of OBO (left) and OBO-Cd^{2+} complex (right).

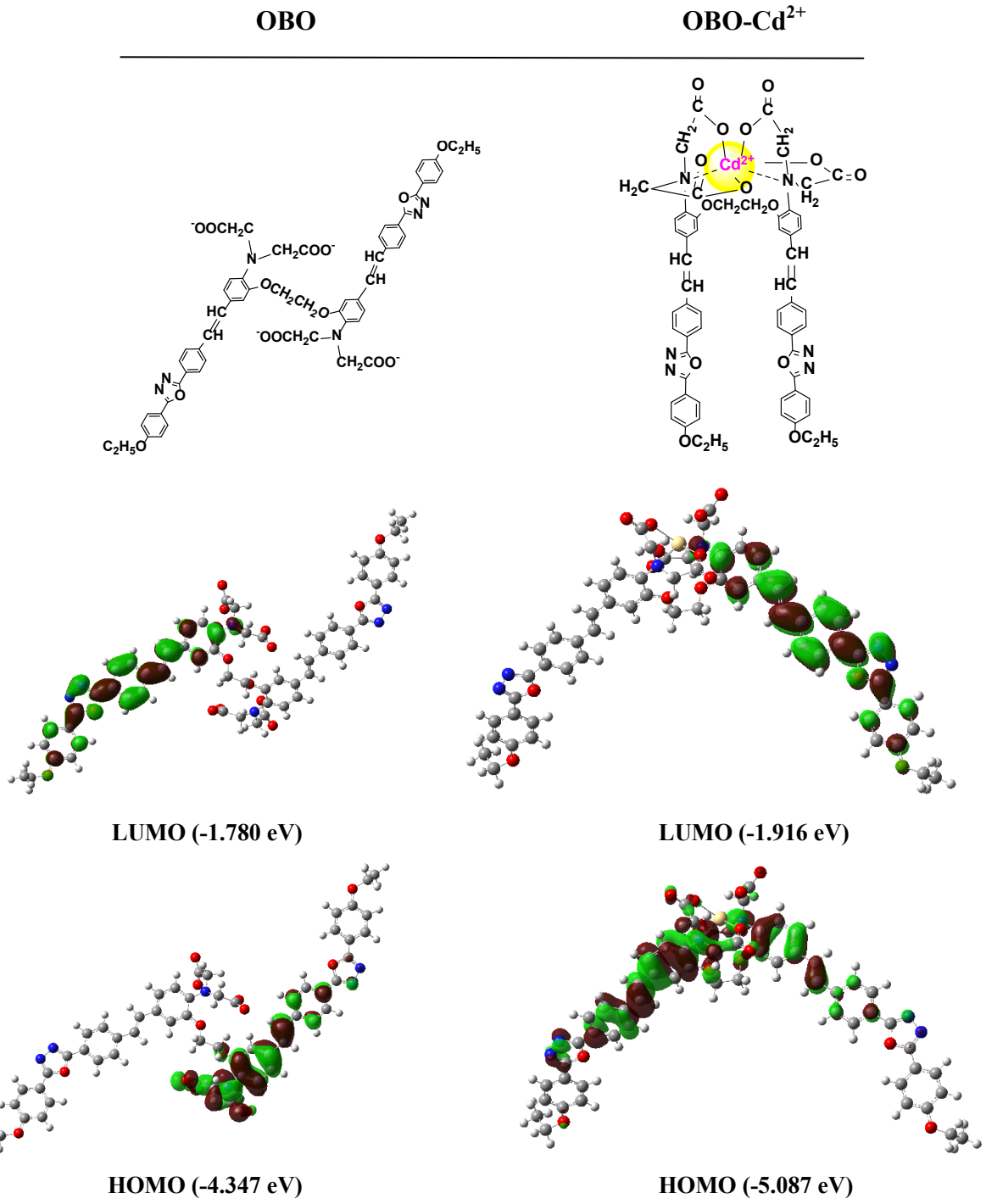


Figure S9. Frontier orbital energy diagrams of OBO and OBO-Cd^{2+}.

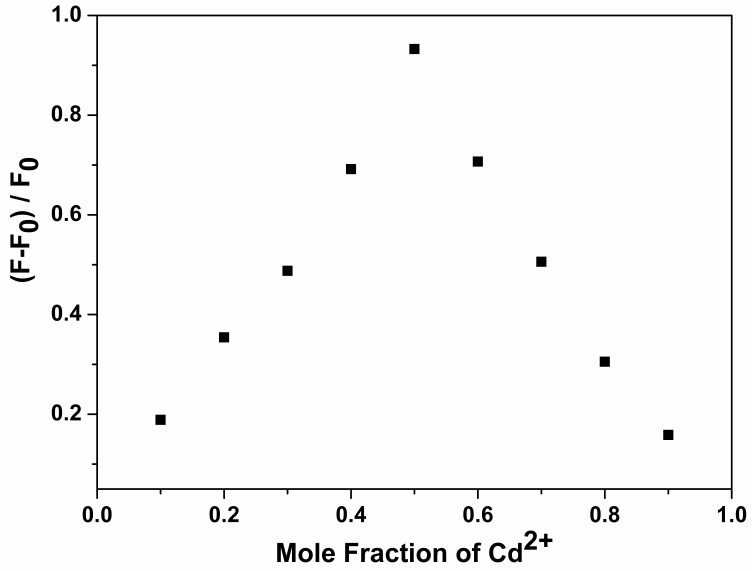


Figure S10. Job plot for determination of the stoichiometry of OBO-Cd^{2+} complex in HEPES buffer solution (50 mM, pH 7.2) containing 0.10 M KCl. The plot of $(F_o - F)/F_o$ against the mole fraction of Cd^{2+}, where F_o and F are the fluorescence intensities of OBO in the absence and presence of Cd^{2+}, respectively. The excitation wavelength is 405 nm.

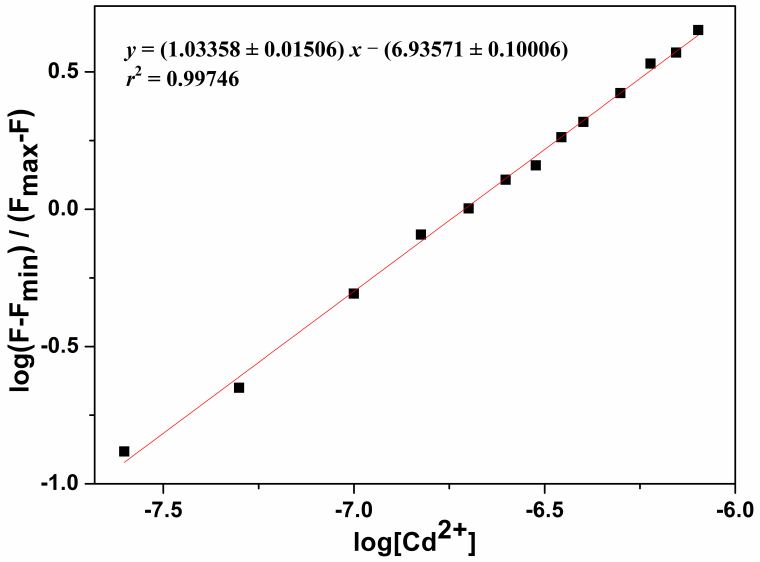


Figure S11. Hill plot for the complex of 1.0 μM OBO with free Cd^{2+} (0.0–1.0 μM) in HEPES buffer solution (50 mM, pH 7.2) containing 0.10 M KCl. The excitation wavelength is 405 nm.

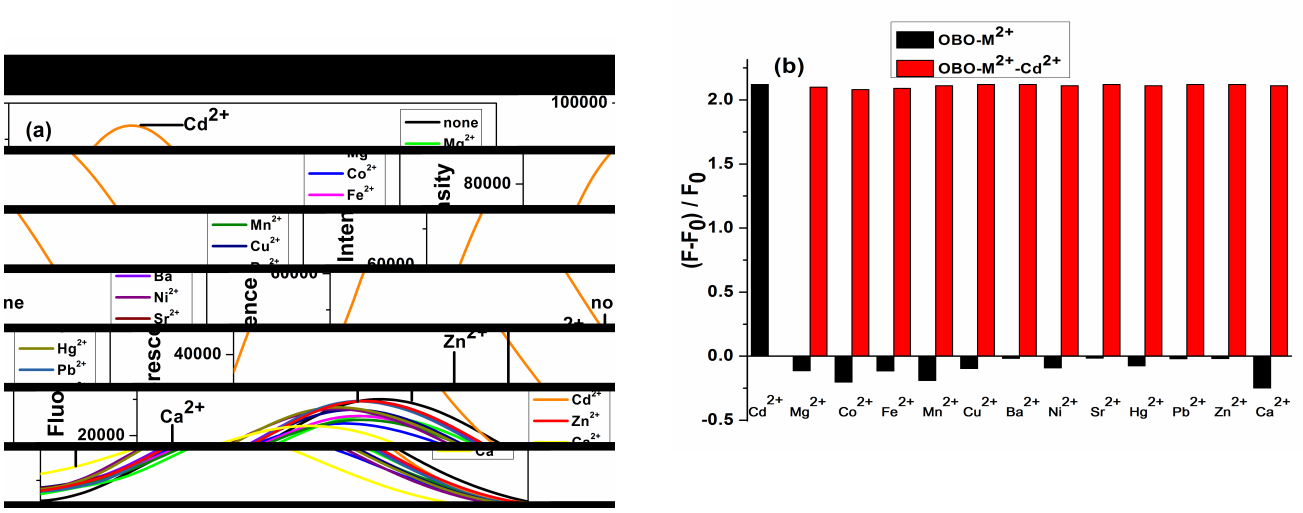


Figure S12. (a) The fluorescence spectra of 1.0 μM OBO in the presence of 1.0 μM Cd^{2+}, 150 μM Mg^{2+}, Co^{2+}, Fe^{2+}, Mn^{2+}, Cu^{2+}, Ba^{2+}, Ni^{2+}, Sr^{2+}, Hg^{2+} Pb^{2+}, Zn^{2+}, and Ca^{2+} in 50 mM HEPES (pH 7.2) containing 0.10 M KCl. (b) Relative fluorescence intensity of 1.0 μM OBO in the presence of 150 μM Mg^{2+}, Co^{2+}, Fe^{2+}, Mn^{2+}, Cu^{2+}, Ba^{2+}, Ni^{2+}, Sr^{2+}, Hg^{2+}, Pb^{2+}, Zn^{2+}, and Ca^{2+} (black bars) followed by adding 1.0 μM Cd^{2+} (red bars) in 50 mM HEPES (pH 7.2) containing 0.10 M KCl. F_o and F are the fluorescence intensities of OBO in the absence and presence of bivalent metal ions, respectively. The excitation wavelength is 405 nm.

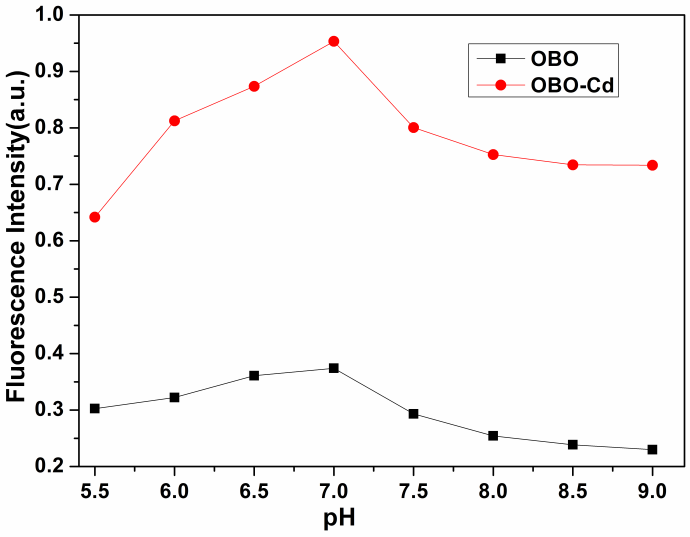
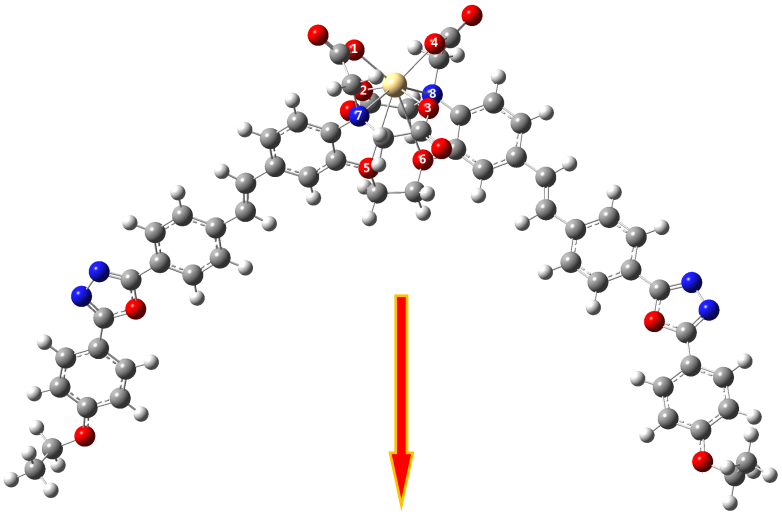


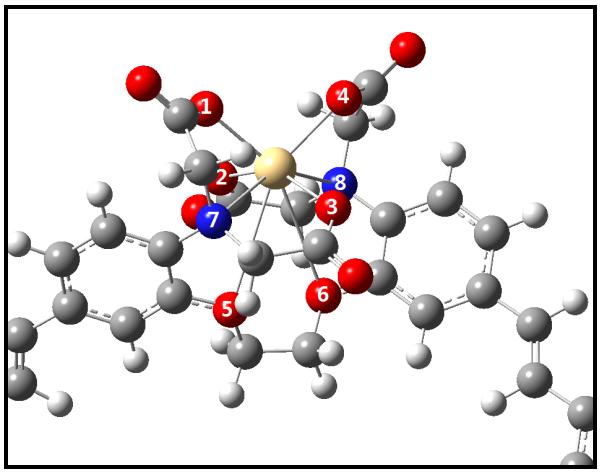
Figure S13. Fluorescent pH titration of free OBO and OBO-Cd^{2+} complex in HEPES buffer solution (50 mM, pH 7.2) containing 0.10 M KCl. The fluorescence intensity increases with pH from 5.5 to 7.0 and then decreases from 7.5 to 9.0. The excitation wavelength is 405 nm.

This journal is © The Royal Society of Chemistry 2014

Table S1. Main Bond Length Parameters of OBO-Cd^{2+}

Parameters	Å
O_1−Cd	2.280
O_2−Cd	2.265
O_3−Cd	2.259
O_4−Cd	2.276
O_5−Cd	3.464
O_6−Cd	3.436
N_7−Cd	2.799
N_8−Cd	2.787





This journal is © The Royal Society of Chemistry 2014

Table S2. Ground-state energies and Cartesian coordinates of OBO in water at the B3LYP/LanL2DZ+6-31G* level. E= -3621.22339927 au.

ATOM	X	Y	Z
C	1.289746	3.689626	-0.0039
C	0.915206	5.064108	0.141878
C	1.974709	6.00218	0.080422
C	3.290136	5.617477	-0.14493
C	3.647099	4.266613	-0.31115
C	2.605858	3.315895	-0.22326
N	-0.38996	5.453812	0.382701
C	-0.65143	6.819823	0.822687
C	0.080288	7.30035	2.118598
O	0.348039	6.444261	2.997023
O	0.278653	8.546508	2.162795
C	-1.49919	4.833717	-0.35838
C	-2.62131	4.172608	0.494344
O	-3.28814	3.286776	-0.11298
O	-2.80596	4.60502	1.660159
O	0.319574	2.720079	0.19057
C	0.153773	1.754037	-0.85609
C	-0.89025	0.748654	-0.41749
O	-0.28239	-0.11862	0.545122
C	-0.93448	-1.26361	0.919141
C	-2.30782	-1.41835	0.806087
C	-2.96938	-2.56936	1.298008
C	-2.17661	-3.54567	1.923058
C	-0.79564	-3.41172	2.018311
C	-0.11589	-2.29118	1.498891
N	1.26226	-2.15325	1.584559
C	2.001153	-3.07678	2.440069
C	1.577991	-3.13472	3.942765
O	1.835273	-4.23431	4.507083
O	1.081209	-2.10088	4.45286
C	2.015429	-1.72857	0.391759
C	3.016368	-0.5541	0.58376
O	3.403031	-0.26575	1.739861
O	3.383271	-0.02084	-0.51059
H	-0.46093	7.550792	0.018496
H	-1.72213	6.85329	1.046255
H	-1.97724	5.618855	-0.96952
H	-1.11142	4.104004	-1.06494
H	3.038066	-2.72621	2.420923
H	1.997658	-4.10163	2.030932
H	1.324308	-1.46282	-0.40405
H	2.592654	-2.59295	0.020214

This journal is © The Royal Society of Chemistry 2014

H	1.752031	7.054993	0.209347
H	4.061816	6.38326	-0.19701
H	2.833254	2.25438	-0.28663
H	-0.19406	2.255368	-1.77077
H	1.09763	1.240364	-1.0683
H	-1.75525	1.279702	-0.00226
H	-1.21976	0.162189	-1.28617
H	-2.88876	-0.61384	0.369854
H	-2.65045	-4.43839	2.325335
H	-0.22463	-4.19729	2.498819
C	5.040087	3.898732	-0.52185
H	5.724944	4.745373	-0.58102
C	-4.40656	-2.77292	1.211309
H	-4.74947	-3.69011	1.689053
C	5.53351	2.638698	-0.62612
H	4.850203	1.792349	-0.54358
C	-5.32684	-1.97126	0.619698
H	-4.99446	-1.05892	0.127043
C	6.930192	2.265163	-0.81306
C	7.260297	0.890907	-0.80811
C	7.990022	3.185317	-0.99476
C	8.568687	0.453305	-0.96047
H	6.460988	0.166167	-0.67601
C	9.297865	2.756308	-1.14929
H	7.785105	4.251363	-1.01532
C	9.610179	1.381965	-1.13092
H	8.788733	-0.60943	-0.94655
H	10.09608	3.4795	-1.28399
C	-6.76636	-2.20032	0.562188
C	-7.57983	-1.27479	-0.12742
C	-7.41337	-3.30573	1.164361
C	-8.95625	-1.43523	-0.21871
H	-7.11407	-0.41342	-0.59928
C	-8.78501	-3.47314	1.078067
H	-6.83403	-4.04294	1.711012
C	-9.58068	-2.53996	0.384108
H	-9.25944	-4.3283	1.548753
C	10.98813	0.952317	-1.28213
O	11.2878	-0.38107	-1.21594
C	12.64336	-0.41067	-1.38461
C	-11.017	-2.73542	0.30782
O	-11.7864	-1.83088	-0.37102
C	-13.0526	-2.32644	-0.23471
N	12.05988	1.672551	-1.47613
N	13.13272	0.788687	-1.54214
N	-11.743	-3.69545	0.813199

This journal is © The Royal Society of Chemistry 2014

N	-13.0625	-3.43024	0.461516
C	13.33651	-1.68758	-1.36384
C	12.63957	-2.8962	-1.17818
C	14.73027	-1.72972	-1.52405
C	13.32023	-4.10318	-1.15466
H	11.562	-2.88648	-1.05184
C	15.42047	-2.93726	-1.50005
H	15.27795	-0.80357	-1.66506
C	14.71694	-4.13972	-1.31613
H	12.78911	-5.03906	-1.01329
H	16.4967	-2.9291	-1.62135
C	-14.1666	-1.61684	-0.83965
C	-13.9707	-0.42872	-1.56822
C	-15.4704	-2.11861	-0.70356
C	-15.0478	0.230783	-2.13879
H	-12.9711	-0.02341	-1.68539
C	-16.5562	-1.46275	-1.2742
H	-15.6321	-3.03534	-0.14585
C	-16.3525	-0.27565	-1.99821
H	-14.9046	1.148507	-2.7002
H	-17.5468	-1.8833	-1.15211
O	15.27306	-5.37787	-1.29169
O	-17.3292	0.46211	-2.58474
C	16.70013	-5.53838	-1.40491
H	16.82382	-6.57609	-1.72408
H	17.08622	-4.89681	-2.20473
C	17.41717	-5.298	-0.08271
H	17.30389	-4.26556	0.261912
H	17.02406	-5.96577	0.690554
H	18.48679	-5.50181	-0.20347
C	-18.702	0.028349	-2.53034
H	-18.947	-0.30868	-1.51707
H	-19.2738	0.939149	-2.7239
C	-19.0173	-1.0319	-3.57754
H	-18.7806	-0.65988	-4.5795
H	-18.4526	-1.95396	-3.40882
H	-20.085	-1.27481	-3.54303
H	-9.55063	-0.70399	-0.75702

This journal is © The Royal Society of Chemistry 2014

Table S3. Ground-state energies and Cartesian coordinates of OBO-Cd^{2+} in water at the B3LYP/LanL2DZ+6-31G* level. E= -3669.13257185 au.

ATOM	X	Y	Z
Cd	-0.13046	-5.36579	0.155893
C	-1.98704	-2.68079	-1.82316
C	-2.01105	-3.96921	-2.44181
C	-3.25039	-4.42654	-2.90972
C	-4.40402	-3.64712	-2.81069
C	-4.37314	-2.36663	-2.24251
C	-3.13225	-1.90052	-1.75077
N	-0.8346	-4.75908	-2.48411
C	-0.9929	-6.1457	-2.93674
C	-1.78084	-7.06511	-1.97277
O	-1.53972	-6.92759	-0.72234
O	-2.54402	-7.90435	-2.48116
C	0.368818	-4.14024	-3.07685
C	1.691407	-4.42885	-2.33009
O	2.724368	-4.0512	-2.91008
O	1.647868	-5.01412	-1.19131
O	-0.78102	-2.29467	-1.3081
C	-0.68385	-1.11019	-0.52164
C	0.697584	-1.1054	0.103039
O	0.720755	-2.1613	1.058598
C	1.89032	-2.51706	1.669243
C	3.084616	-1.83105	1.500747
C	4.279761	-2.27922	2.109433
C	4.216638	-3.44905	2.878582
C	3.012634	-4.1279	3.073265
C	1.816155	-3.6768	2.501069
N	0.580999	-4.35553	2.654468
C	0.627689	-5.64788	3.347891
C	1.360768	-6.77538	2.581483
O	2.038336	-7.57302	3.251869
O	1.167217	-6.83106	1.316477
C	-0.5702	-3.54238	3.102619
C	-1.88579	-3.75899	2.32106
O	-1.89631	-4.5637	1.325569
O	-2.8636	-3.11599	2.743116
H	-1.43432	-6.20459	-3.94142
H	0.017606	-6.56301	-3.00666
H	0.488313	-4.47606	-4.11652
H	0.25145	-3.05901	-3.11008
H	-0.41234	-5.97352	3.461124
H	1.048963	-5.56011	4.359257
H	-0.32805	-2.48369	3.03555

This journal is © The Royal Society of Chemistry 2014

H	-0.77378	-3.74663	4.162966
H	-3.32948	-5.41699	-3.34115
H	-5.34353	-4.04354	-3.18706
H	-3.07403	-0.92242	-1.2895
H	-0.81026	-0.21756	-1.14769
H	-1.45048	-1.10653	0.262526
H	1.462523	-1.26524	-0.66662
H	0.879885	-0.13827	0.589132
H	3.102341	-0.9488	0.872522
H	5.120162	-3.8311	3.346693
H	3.016382	-5.03194	3.670053
C	-5.60947	-1.5928	-2.16373
H	-6.47427	-2.09658	-2.59301
C	5.560466	-1.59181	1.966978
H	6.389698	-2.09781	2.458958
C	-5.77511	-0.36622	-1.61658
H	-4.9161	0.136326	-1.17538
C	5.800338	-0.42844	1.318742
H	4.972525	0.090373	0.838355
C	-7.02347	0.388763	-1.52604
C	-7.01968	1.627088	-0.85028
C	-8.25089	-0.05035	-2.07363
C	-8.17425	2.38797	-0.71328
H	-6.08988	1.991944	-0.42175
C	-9.40668	0.702503	-1.94256
H	-8.30148	-0.99266	-2.60966
C	-9.38668	1.933139	-1.25693
H	-8.1386	3.334376	-0.18376
H	-10.3397	0.347246	-2.36794
C	7.089869	0.248389	1.191694
C	7.144148	1.487357	0.519387
C	8.301693	-0.26552	1.708131
C	8.336109	2.186165	0.370565
H	6.228864	1.906461	0.109615
C	9.494395	0.424501	1.564331
H	8.311633	-1.21847	2.227307
C	9.529815	1.663085	0.893842
H	10.41372	0.013345	1.968469
C	-10.6118	2.702598	-1.12201
O	-10.5926	3.884144	-0.43483
C	-11.8877	4.312654	-0.50512
C	10.79111	2.371494	0.758106
O	10.82197	3.576434	0.113233
C	12.13759	3.937836	0.180021
N	-11.8058	2.431564	-1.5731
N	-12.6333	3.474666	-1.17354

This journal is © The Royal Society of Chemistry 2014

N	11.97622	2.025203	1.180522
N	12.8493	3.039802	0.806045
C	-12.2614	5.564033	0.131234
C	-11.3147	6.350227	0.815016
C	-13.5925	6.006521	0.073591
C	-11.6938	7.539111	1.418279
H	-10.2807	6.026396	0.871697
C	-13.9806	7.197909	0.678186
H	-14.3306	5.406472	-0.44868
C	-13.029	7.978864	1.356783
H	-10.9696	8.151796	1.945453
H	-15.0179	7.503481	0.617688
C	12.56494	5.194554	-0.41023
C	11.65221	6.050686	-1.05504
C	13.91433	5.575297	-0.33853
C	12.08229	7.246734	-1.608
H	10.60481	5.775412	-1.12156
C	14.35287	6.774865	-0.88993
H	14.62521	4.923218	0.158429
C	13.43602	7.623438	-1.53425
H	11.38536	7.911413	-2.10837
H	15.4006	7.037276	-0.81013
O	-13.2798	9.163744	1.968222
O	13.74398	8.805709	-2.12422
C	-14.6159	9.700322	1.99986
H	-14.4678	10.76544	2.193699
H	-15.0811	9.604075	1.012548
C	-15.4672	9.07211	3.09625
H	-15.6269	8.002713	2.927295
H	-14.9871	9.200217	4.071752
H	-16.4464	9.562692	3.126371
C	15.09081	9.314043	-2.0795
H	15.80148	8.510435	-2.3022
H	15.13023	10.02922	-2.9047
C	15.40557	10.00535	-0.75873
H	14.69161	10.81414	-0.57255
H	15.36805	9.30985	0.085404
H	16.41196	10.43626	-0.80116
H	8.34349	3.137949	-0.15044