Synthesis, Characterization and Chelation Behavior to Lanthanides Cations of New Metal Free Phthalocyanines Bearing Coumarins Derivatives

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ABSTRACT: Novel tetrasubstituted metal-free phthalocyanines were synthesized by the cyclotetramerization reaction of the phthalonitrile derivatives. The new compound were characterized by a combination of IR, ^{1}H NMR, ^{13}C NMR, UV Vis, Elemental analysis and MS spectra data. The complexation properties of the new metal-free phthalocyanines towards lanthanides cations have been investigated in Dimethyl sulfoxide (DMSO) by means of UV spectrophotometry absorption and conductivity. The stoichiometries of complexes formed are ML or M_2L in some cases. Therefore, the stability profile of mononuclear complexes 11-12 formed illustrates a little selectivity of PcH_2 11 towards Y^{3+} and of PcH_2 12 towards Gd^{3+}.

Keywords: Stoichiometries; Complexation; Stability constants, Cation binding properties.

INTRODUCTION: PcH_2 can be prepared from a number of ortho-disubstituted benzene derivatives such as phthalonitrile, phthalimide, phthalic anhydride and 1,3-diiminoisoindoline[1-8].

Phthalonitrile (**4**) and 1,3-diiminoisoindoline (**5**) are two common types of starting materials used to prepare metal free Pcs (PcH_2). A typical synthetic procedure for preparing PcH_2 involves the condensation of phthalonitrile to dilithium PC ($PcLi_2$) by refluxing phthalonitrile and lithium metal in pentanol. $PcLi_2$ is then treated with dilute acid, to give PcH_2 in yields up to 60%.

Scheme 1: The procedure for the cyclotetramerisation of phthalonitrile to form metal-pee PcH_2. i) Lithium, reflux; pentanol. ii) Heat in a high boilingpoint solvent with urea. iii) Treat with acid. iv) Heat; 1, 8-diazabicyclonon-5-ene (DBN); pentanol. (Or dimethylaminoethanol (DMAE) and pentanol). v) Sodium metal (Na); ammonia (NH_3); Methanol.

Alternatively, phthalonitrile can also be converted to 1, 3-diiminoisoindoline (**5**), by the reaction of phthalonitrile with ammonia and sodium metal in methanol under mild conditions (**Scheme 1**). The 1,3-diiminoisoindoline (**5**) is then condensed in a reducing solvent such as dimethylaminoethanol (DMAE), to produce PcH_2. Non-nucleophilic hindered bases such as 1,s-diazabicyclonon-5-ene (DBN) and 1,sdiazabicyclo [5.4.0] undec-7-ene (DBU) can also

be used for the preparation of metal-free Pcs from phthalonitriles in either a melt or in pentanol solution.[9-11] In this paper, we describe the synthesis and characterization of metal-free phthalocyanine (**4-5**), which was accomplished in DBU and *DMAE* in a Schlenk tube under N_2 atmosphere. In addition the complexation properties of new metal-free phthalocyanines **11-12** towards lanthanides cations have been investigated in Dimethyl sulfoxide (DMSO) by means of UV spectrophotometry absorption and conductivity.

MATERIALS AND METHODS:

Instrument and Materials: The UV spectra were recorded on Perkin Elmer Lambda 24 spectrophotometer. DMSO (SDS for HPLC, 0.03% water content) is commercial and used without further purification. The supporting electrolyte used in the stability constant determinations was NEt_4Cl_4 (Acros Organics). The metal salts chosen were chlorides (Fluka, purum).

Stability Constant Measurements: The stability constants β_{xy} being the concentration ratios $[M_xL_y^{xn+}]/[M^{n+}]^x[L]^y$ and corresponding to the general equilibrium:

$$y\,L + x\,M^{n+} \longleftrightarrow M_xL_y^{xn+}$$

(Where; M^{n+} = metal ion, L = ligand) were determined in DMSO by UV-absorption spectrophotometry at 25°C.

The ionic strength has been maintained at 0.01 mol.L^{-1} using Et_4NCl_4. The concentration of ligand solutions is ranging between 10^{-4} and 5×10^{-5} mol.L^{-1} and the UV spectra has been recorded between 270 nm and 800 nm. Generally the metal to ligand ratio R at the end of the titration did not exceed 15 and the equilibriums were quasi-instantaneous for all the systems.

The titration of the ligand by the metal solution induced spectra changes, large enough to allow the analysis of the resulting data using the program "Letagrop".[16] The stability constants of the various species and their molar absorption coefficients are deduced from the best fit between the experimental and calculated UV spectra. The best fit is reflected by the lowest value of U (the sum of U values for all given lambda) corresponding to the square sum of a differences between experimental and calculated absorbances ($U = \Sigma\,(A_{cal} - A_{exp})^2$). The β_{xy} values correspond to the arithmetic means of at least three independent experiments.

Conductimetric studies: While complexation by a neutral ligand is not expected to dramatically alter the molar conductivity of a cationic species, the differences can usually be detected and so the measurement of conductance of a solution of a metal ion into which a ligand is added can be a useful rapid means of establishing the stoichiometry of a complex ion species. Thus, this procedure was followed to obtain preliminary estimates of the metal:ligand ratio in the complexes formed by the Pc.[17]

Experimental section: All reagents were obtained from Fluka and Aldrich. The purity of the products was tested in each step by TLC (SiO_2, $CHCl_3$/MeOH and THF/MeOH). Melting points were determined using an Electrothermal apparatus and are uncorrect-ed. ^1H NMR and ^{13}C NMR spectra were carried on a Varian Gemini 300 (300 MHz) spectrometer using TMS as internal standard (δ = 0 ppm). IR spectra were recorded on a Perkin-Elmer 398 Spectrophotometer. MS were recorded on a LC-MS-MS 8030 Shimadzu. Elemental analyses were performed on Perkin-Elmer 2400 elemental analyzer, and the values found were within ±0.3% of the theoretical values. The UV spectra were recorded on a Perkin Elmer Lambda 11 spectrophotometer.

Synthesis of 4-(2-Oxo-2H-chromen-7-yloxy)-phthalonitrile 9: 4-Nitrophthalonitrile (2.25 g, 12.34 mmol) was dissolved in dry DMF (15 mL) under argon and 7-Hydroxycoumarin (2.00 g, 12.34 mmol) was added. After stirring for 15 min at room temperature, finely ground anhydrous potassium carbonate (3.67 g, 26.6 mmol) was added in portions during 2 h with efficient stirring. The reaction mixture was stirred under argon atmosphere at room temperature for 24 h after which time, the ensuing mixture was poured into 100 mL iced water and the precipitate filtered off, washed with methanol and then dried. The crude product was chromatographered over a silica gel column using a mixture of $CHCl_3$: MeOH (100:5 (v:v)) as eluent, giving a powder of 4-(2-Oxo-2H-chromen-7-yloxy)-phthalonitrile **9**.

Yield: (74%). M.p= 325°C FT-IR (KBr) ν cm-1: 3075 (Ar-CH), 2225 (CN), 1602 (C=C), 1731 (C=O, lactone and ester), 1496 (C-O-C). ^1H NMR. (DMSO-d_6, 300 MHz) (δ : ppm) 6.47–8.18 (m, 8H, Harom+H_3). ^{13}C-NMR (DMSO-d_6, 75 MHz) (δ: ppm) 157.3(C_2), 155.4(C_4), 108.2(C_3), 115.6(CN), 115.7(CN), 109.8-160.2(Carom). Calcd for $C_{17}H_8O_3N_2$: C, 70.83; H, 2.79; N, 9.71. Found: C, 70.80; H, 2.7; N, 9.7; MS (LC-MS) m/z: Calc. 287.2; Found: 287.2

Synthesis of 4-(4-Methyl-2-oxo-2H-chromen-7-yloxy)-phthalonitrile 10: The synthesis of 2 was similar to that of **1**, except 7-hydroxy-4-methylcoumarin (1.232 g, 7 mmol) was employed instead of 7-hydroxycoumarin. The amounts of the other reagents were: 4-nitrophthalonitrile, 0.865 g (5 mmol) and anhydrous potassium carbonate, 1.035 g (7.55 mmol). Yield: (75%). M.p= 330°C.

FT-IR (KBr) ν cm-1: 3079 (Ar-CH), 2227 (CN), 1610 (C=C), 1735 (C=O, lactone and ester), 1495 (C-O-C). ^1H NMR.(DMSO-d_6, 300 MHz) (δ : ppm) 2.42 (s, 3H, CH_3), 7.43-8.11 (m, 7H, H_{arom}+$H_{2,3}$). ^{13}C-NMR (DMSO-d_6, 75 MHz) (δ: ppm) 18.5(CH_3), 159.8(C_2), 153.2(C_4), 108.6(C_3), 115.4(CN), 115.7(CN), 116.2-161.7(Carom). Calcd for $C_{18}H_{10}O_3N_2$: C, 71.52; H, 3.33; N, 9.26. Found: C, 71.5; H, 3.3; N, 9.2

MS (LCMS-MS) m/z: Calc. 302.284; Found: 302.2: m/z [M] $^{+\cdot}$

General procedure for the synthesis of metal-free 11,12: A mixture of 4-(2-Oxo-2H-chromen-7-yloxy)-phthalonitrile **9** (0.25 g,0.487 mmol) and 4-(4-Methyl-2-oxo-2H-chromen-7-yloxy)-phthalonitrile **10** and catalytic amount of 1.8-diazabicyclo[5.4.0]undec-7-ene (DBU) in 2.5 ml of DMAE was heated and stirred at 150 °C in a sealed glass tube for 24 h under N$_2$. After cooling to room temperature the green crude product was precipitated with ethanol, filtered and washed first with ethanol then diethyl ether and then dried in vacuo. Finally, pure metal-free phthalocyanines **11-12** was obtained by column chromatography which is placed aluminum oxide using CHCl$_3$:CH$_3$OH (99:1) as solvent system.

Metal free Pc (11):
Yiled: 63%
M. P.: = 335°C
FT-IR (KBr, vmax, cm^{-1}): 3276 (N-H); 3071 (C-H$_{arom}$); 1471 (C-C); 1265 (C-N); 1602 (C=C); 1208 (C-O$_{lactone}$); 1725 (C=O$_{lactone}$)
Calc. for C68H34N8O12: C, 70.71; H, 2.96 N, 9.701, Found: C, 70.7; H, 2.9, N, 9.7;
^{1}H NMR (DMSO-d$_6$, 300 MHz) (δ: ppm):
2.42(s,12H,CH$_3$),8.32–8.42 (m, 28H, Harom+ H$_{3,4}$),
UV/Vis (DMSO, λmax nm (log ε)): 339 (4.729), 593 (4.535), 620 (4.633) , 660 (5.005) , 704 (5.066)

Metal free Pc (12):
Elution solvent system: Chloroform: methanol (100:2) as eluent. Yield: 113 mg (77%).
M. P.: =315°C
FT-IR (KBr, vmax, cm-^{1}): 3418 (N-H); 3019 (C-H$_{arom}$); 1489 (C-C); 1276 (C-N); 1612 (C=C); 1214 (C-O$_{lactone}$); 1731 (C=O$_{lactone}$)
Calc. for C72H42N8O12: C, 71.401; H, 3.495, N, 9.252 Found: C, 71.4; H, 3.4, N, 9.1;
^{1}H NMR (DMSO-d$_6$, 300 MHz) (δ: ppm): 7.92-8.40 (m, 32H, Harom+H$_{3,4}$),
UV-vis (DMSO) λmax/nm: 331 (4.531), 601 (4.201), 628 (4.408), 664 (4.758), 710 (5.010).

RESULTS AND DISCUSSION:
Phthalonitrile derivatives (**9** and **10**) were synthesized through base-catalyzed aromatic nitro displacement of 4-nitrophthalonitrile with 7-hydroxycoumarin using K$_2$CO$_3$ as a base in anhydrous DMF[12-14]. The reactions were carried out at room temperature under N$_2$ atmosphere for 24 h.
The 4-(4-Methyl-2-oxo-2H-chromen-7-yloxy)-phthalonitrile **10** was synthesized by heating 4-methyl-7-hydroxycoumarin and 4-nitrophthalonitrile in the presence of K$_2$CO$_3$ as a base in dry DMF at 50 °C for 24 h. Scheme 2.

Characterization of the products involved a combination of methods, including elemental analysis, FT-IR, UV–Vis and ^{1}H NMR spectroscopy. The spectroscopic data of the new compounds are consistent with their proposed structures.
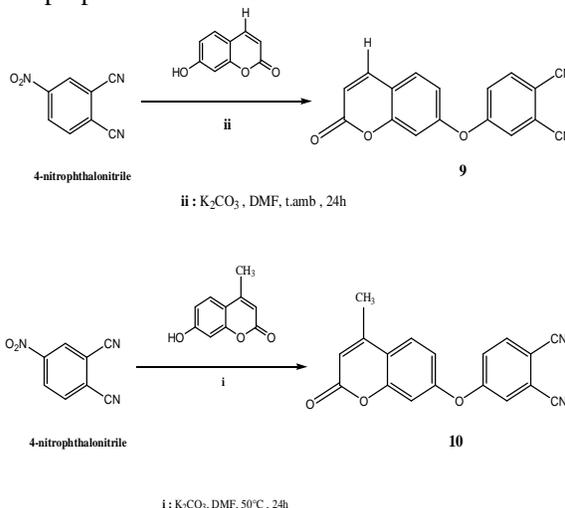
Scheme 2: Protocol synthesis of phthalonitriles 9-10.

In the IR spectrum of compound **9**, stretching vibrations of CN (2225 cm–1) and aliphatic CH (2925–2896 cm^{-1}) appeared at the expected frequencies. In the ^{1}H NMR spectrum of **9**, the OH group of 7-hydroxycoumarin disappeared, as expected. In the ^{13}C NMR spectrum of **9** the presence of nitrile carbon atoms was indicated, with peaks at δ 115.6 and 115.7 ppm. In the mass spectrum of compound **9**, the presence of a molecular ion peak at m/z = 287.2 [M]$^+$ confirmed the proposed structure.

The sharp peak in the IR spectrum for the CN vibration of phthalonitrile **10** at 2227cm^{-1} disappeared after conversion into the metal-free phthalocyanine, indicative of metal-free phthalocyanine formation.

The mass spectra of **10** confirmed the proposed structure; the molecular ions were easily identified at 302.2 [M+] For compound **10**.

The preparation of phthalocyanine derivatives from the aromatic nitriles occurs under different reaction conditions. For various substituted dinitriles, the reaction in the presence of strong non-nucleophilic bases such as DBU or 1,5-diazabicyclo[4.3.0]non-5-ene (DBN) either in n-pentanol or in bulk is most efficient in comparison to other methods. In addition, these reactions are easy to perform, work under relatively mild conditions and yield pure phthalocyanines [15].

The self-condensation of the dicyano compounds **9-10** in a high-boiling solvent in the presence of a few drops 1,8-diazabicyclo[5.4.0] undec-7-ene (DBU) as a strong base at reflux temperature under a nitrogen

atmosphere afforded the metal-free phthalocyanines **11-12** as a green solids after purification by column chromatography (aluminum oxide) using CHCl$_3$:CH$_3$OH (100:4) as the solvent system (Scheme 3).

The structures of the target compounds were confirmed using IR, ^{1}H NMR, ^{13}C NMR and mass spectral data. All the results were consistent with the predicted structures as shown in the experimental section.

FT-IR spectra of the new metal-free phthalocyanines **11-12** clearly indicate the cyclotetramerization of the phthalonitrile derivatives **9-10** with the disappearance of the characteristic CN peaks. In the ^{1}H NMR spectra of compounds **11**and **12** disappearance of the OH peak at 10.40 ppm and appearance of the extra aromatic peaks at 8.32–8.42 and 7.92-8.40 ppm and a singlet at 2.42 for compound **11** were certainly defined structures.

R = CH$_3$ (**10**)

R = H (**9**)

R = CH$_3$ (**11**)

R = H (**12**)
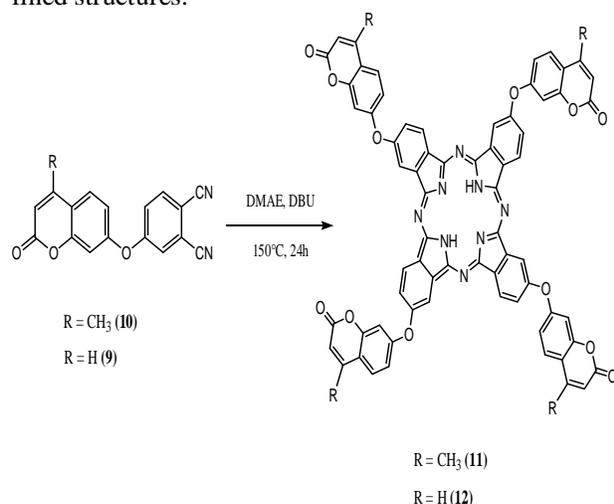
Scheme 3: Synthesis of metal-free phthalocyanines 11-12.

Complexation followed by Spectrophotometry UV: The complexation studies of ligands **11**, **12** with lanthanides cations were followed. The variation of spectrum during the titration indicates generally the formation of a new species. In fact, the recording of a solution containing compounds **11**, **12** separately and free illustrates the existence of three maximums of absorbance at around 290, 360 and 692 nm and a shoulder at 620 nm (Figures 1, 2). The titration by metal solution involves a decrease in absorbance and in some cases an isobestic point will appear as shown on the Figure 1. The later is corresponding to the complexation of cerium by compound **11**. Moreover, two isobestic points appear at 285 and 315 nm respectively.

After spectrophotometric data treatment, species of formed complex and their stability constants were obtained harvested in the following table 1.
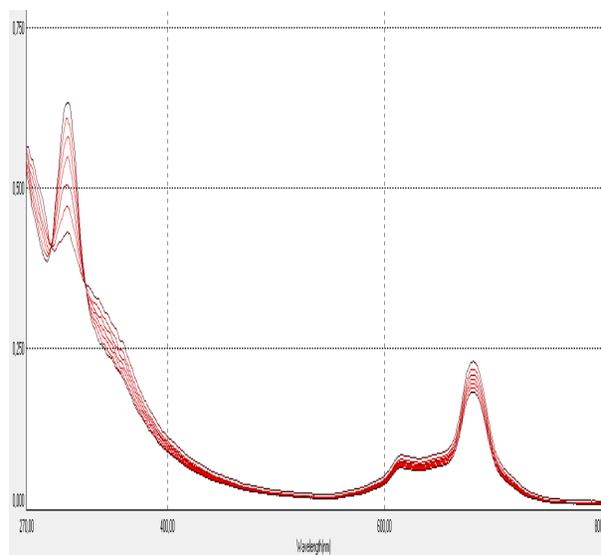
Figure 1: UV absorption spectra of complexation of Ce^{3+} by compound 11 in DMSO, CL = 5×10^{-5} M, 0 ≤ RM/L ≤ 5, at 25. °C.
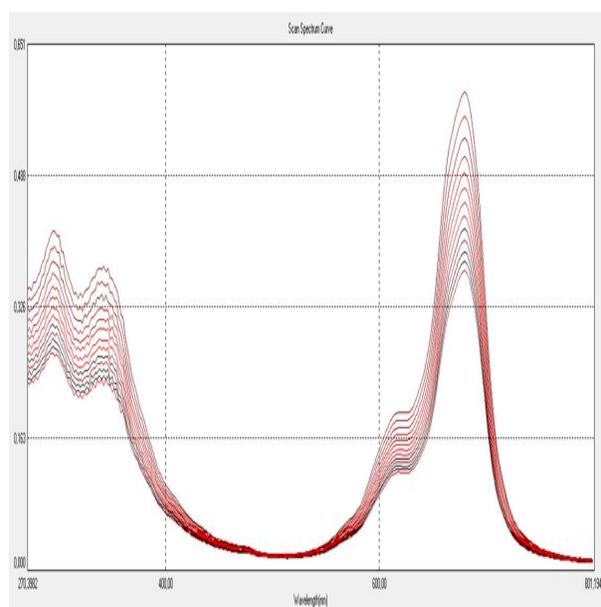
Figure 2: UV absorption spectra of complexation of Gd^{3+} by compound 12 in DMSO, CL = 5×10^{-5} M, 0 ≤ RM/L ≤ 5, at 25 °C.

Table 1: Stability constants (log $\beta \pm \sigma n^{-1}$) of complexes of lanthanide cations 11-12, in DMSO, at 25 °C, I = 10^{-2} M.

	M:L	Y^{3+}	Gd^{3+}	Eu^{3+}	Ce^{3+}	La^{3+}	Nd^{3+}
11	1:1	4,24± 0,06	3,24± 0,08	2,49± 0,02	6,77± 0,09	6,15± 0,07	6,83± 0,06
	2:1						
12	1:1	3,58± 0,01	4,5±0, 03	3,12± 0,01	4,18± 0,07	3,73± 0,08	3,62± 0,04

From these results, we plotted the mononuclear complexes formed with stability profiles compounds 11 and **12** in Figure 3.
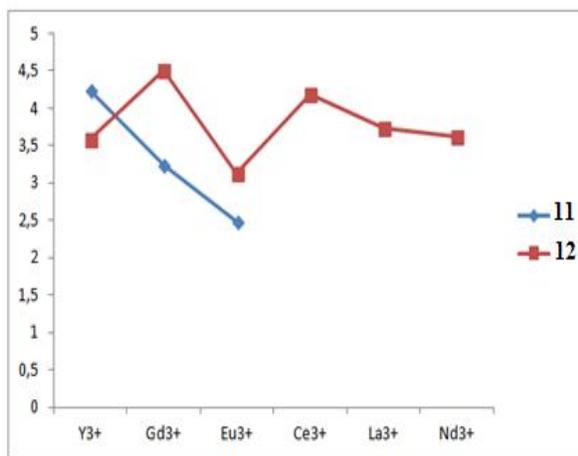
Figure 3: Profiles of stability of ML complexes 11-12.

Figure 5: Conductometric titration (left) 11 with Eu^{3+} (right) 12 with La^{3+} (C$_L$= 5 x 10^{-5}M).

By observing the stability profiles of mononuclear species, we notice that in general, the derivative **12** appears to be better complexing with better stability while noting a slight selectivity with respect to gadolinium by **12** and to yttrium by **11**.

This can be explained by the made that the ligand **12** admits a hydroxyl group of more than its counterpart in **11**, understood that the non-binders doublet of the oxygen participates in the chelating phenomena.

We can suggest following proposition of localisation of complexed cation in the ligand cavity (Figure 4). In the other hand, Regarding the stability constant of binuclear complex formed with Ce^{3+}, La^{3+}, Nd^{3+} and ligand **11**, similar stability constant is noted and no particular selectivity shown. We suggest two following proposition of possible localisation of complexed cations in the ligand cavity (Figure 4b).

(a)   **(b)**

Figure 4: Suggestion of cations localization in complexes.

In order to confirm some stoichiometry, we proceed to the conductimetric titration. The ligand was added progressively to the metal solution. The conductance of free cations in the starting solution begins to decrease. The change in slope indicating a formation of a new species. Figure 5 illustrates the formation of a mononuclear complex for the **11**/Y^{3+}, **11**/Gd^{3+} and **11**/Eu^{3+} systems and a binuclear complex for the other.

CONCLUSION: In this study, new metal-free phthalocyanines was synthesized and characterized. The complexation study of lanthanide cations serie (Y^{3+}, Gd^{3+}, Eu^{3+}, Ce^{3+}, La^{3+} and Nd^{3+}) with Pc **11** and Pc **12** shows mononuclear species training in all cases with the exception of the complex **11**/Ce^{3+}, **11**/La^{3+} and **11**/Nd^{3+} , a second cation is trapped by the Pc **11**. The stability profiles of mononuclear complexes formed illustrate a little selectivity of Pc **11** towards Y^{3+} and of Pc **12** towards Gd^{3+}.

The stoechiomtries of some complexes were confirmed by conductometric titration. So, the conductimetric study confirmed the UV Spectrophotometric results. Hence the suggestion of a different rearrangement ligands in space.

REFERENCES:
1. S. A. Mikhalenko; S. V. Barknova; O. L. Lebedev and E. A. Luk' yanets. (1971) *Zhur. Obs. Kh.,* 41, 2735.
2. H. Shirai; A. Maruyama; K. Kobayashi; N. Hojo and K. Urushido. (1980) *Markromol. Chem.,* 181, 575.
3. C. C. Leznoff; S. Vigh; P. I. Svirskashi; S. Greenberg; D. M. Drew; E. Ben-Hur and I. Rosentha. (1989) *Photochem. Photobiol.,* 49, 279.
4. N. Sehlotho and T. Nyokong. (2004) *J. Mol. Str.,* 2 19, 201.
5. J. M.Lehn. (1988) *Angew. Chem. Int. Ed. Engl.,* 27, 89.
6. D. Wolhrle; M. Eskes; K. Shigehara and A. Yamada. (1993) *Synthesis,* 194-196.
7. R. D. Joyner and M. E. Kenney (1962) *Inorg. Chem.,* 1, 236.
8. S. Hayashida and N. Hayashi (1991) *Chem. Mater.,* 41, 1243.

9. D. Wolhrle; M. Eskes; K. Shigehara and A. Yamada. (1993) *Synthesis,* 194-196.

10. M. J. Schneider and M. Hanack. (1984) *Inorga. Chem.,* 23, 1065.

11. J. Yang, Ph.D Thesis, (2006), the school of chemical sciences, Dublin City University.

12. R. Medyouni, A. C. Mtibaa, L. Mellouli, A. Romerosa, N. Hamdi, (2016) J Incl Phenom Macrocycl Chem, 86, , 1-2, DOI 10.1007/s10847-016-0655-7.

13. O. Naouali , B. Mellah , R. Medyouni , N. Hamdi and L. Baklouti , (2015) *Eur. J. Chem.* 6 (3), 337-341.

14. R. Medyouni, N. Hamdi, A. Ben Hsouna, A. S. Al-Ayed, H. A. Soleiman, F. Zaghrouba, and C. Bruneauc, (2013) Heterocycles, 87(11), 2283-2297.

15. F. Hacıvelio glu, M. Durmus, A. G. Gurek, A. Kılıc, Ahsen, (2008) Dyes Pigments. 79, 14–23.

16. G. Sillen, B. Warnquist, (1968) *Ark. Kemi.,* 31 377-390.

17. W. Thabet, L. Baklouti, R. Zieba and S. Parola, (2012) *J. Inclusion. Phenom.*, 73, 135-139.