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Synthesis of BEDT-TTF Donors with Three-Fold Symmetry

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Nottingham

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Acknowledgements

I would like to express my gratitude to all the people that have been helping me and giving me his support. First of all to my supervisor Professor John Wallis for its high degree of involvement in the project and for always being willing to find the solution to the problems encountered during work. I would also like to render thanks to the researcher Songjie Yang for his help and advice throughout the work.

Finally, for all my friends that were in Nottingham and my family for the support in all the moments.

Contents

1. ABSTRACT

The BEDT-TTF derivatives have been a major focus for research in the preparation of molecular conducting systems and radical cation salts. Special attention is given in this work, to the preparation of compounds with more than one unit of BEDT-TTF units with the aim to prepare new materials with different crystal packing arrangements and thus new possible physical properties.

The preparation of a BEDT-TTF or ET derivatives with a hydroxymethyl group (HMET) was carried out successfully and HMET ester of isonicotinic acid was prepared. Only metal complexes with copper ions were prepared and none of them presents more than one ET unit.

Two approaches were proposed for the synthesis of the HMET triester of trimesic acid considering the two key reactions for the preparation of BEDT-TTF derivatives: the coupling reactions and the esterification. The experimentation carried out shows better results when the HMET donor is prepared first and then attached to the central core.

2. INTRODUCTION

2.1 Scope of work

This project has been done in the Natural Science Research Center in Nottingham Trent University.

The research field of the Department of Organic Chemistry is very diverse. The current research is focused on the development of organic conductors and superconductors compounds derived from organosulfur donors. Other areas include the study of the formation of bonds between groups using studies of molecules with partially formed bonds and other aspects of heterocyclic chemistry associated with medical applications.

In the area of organic conductors, where the work was developed, a wide range of new substituted derivatives of the organosulfur donor BEDT-TTF (bis (ethylenedithio) tetrathiafulvalene) has been prepared. Hydroxyl, amino and carboxyl derivatised materials provide both hydrogen bonding for organizing the crystalline state, and also the potential for attachment of new molecular systems bringing new properties. Multi-substituted donors have been prepared, and a new strategy has been developed for providing such materials as one stereoisomer.[1]

2.2 Background

Organosulfur donor molecules have been a major focus for research in the preparation of molecular conducting systems, with tetrathiafulvalene and its derivatives playing a leading role initially.

Following on from the extensive studies on tetrathiafulvalene (TTF), bis(ethylenedithio)tetrathiafulvalene, more commonly known as BEDT-TTF or ET, has played a prominent role in the recent development of molecular conductors, superconductors and bifunctional materials, and a wide range of its radical cation salts have been prepared and their properties investigated.

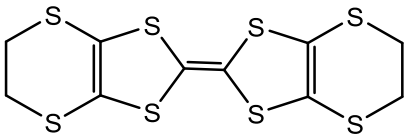


Figure 1. Structural formula of ET

The ET molecule shows two reversible oxidations at 0.50 and 0.91 V relative to the Ag/AgCl electrode, ca. 0.15 V more positive than those for tetrathiafulvalene (TTF), and has been converted into a very large number of radical cation salts.[2]

Attachment of several BEDT-TTFs together has the potential to apply a constraint to the organization of the molecules in the solid state and lead to new crystal packing arrangements, and thus new physical properties, for their radical cation salts.

One way of achieving this is to functionalize BEDT-TTF with a group capable of binding to a metal ion and then form *bis* or *tris* complexes around the metal, and finally oxidize such materials to their radical cation salts.[3] Another way, includes the preparation of molecules with more than one BEDT-TTF units. So far, according to Wang, Q et al.[3] only one molecule with two ET moieties has been reported.[4] Attempts to make systems with more than one donor have faced difficulties.

The synthesis of the BEDT-TTF functionalized derivatives have been reported by several authors[5,6], some of which also includes chiral ones.[2,7,8] The starting material currently used for the synthesis of the BEDT-TTF functionalized derivatives is the tetraethylammonium salt of $[Zn(dmit)]^{2-}$ **1**.

The 1,3-dithiole-2-thione-4,5-dithiolate anion (dmit) is obtain by reduction of carbon disulfide with sodium in DMF. Treatment of the reduction products with zinc chloride and tetraethylammonium bromide produces an insoluble tetraethylammonium zincate salt that can be isolated by filtration and washed with different solvents without further purification steps.[9,10] The synthetic pathway is shown in Figure 2.

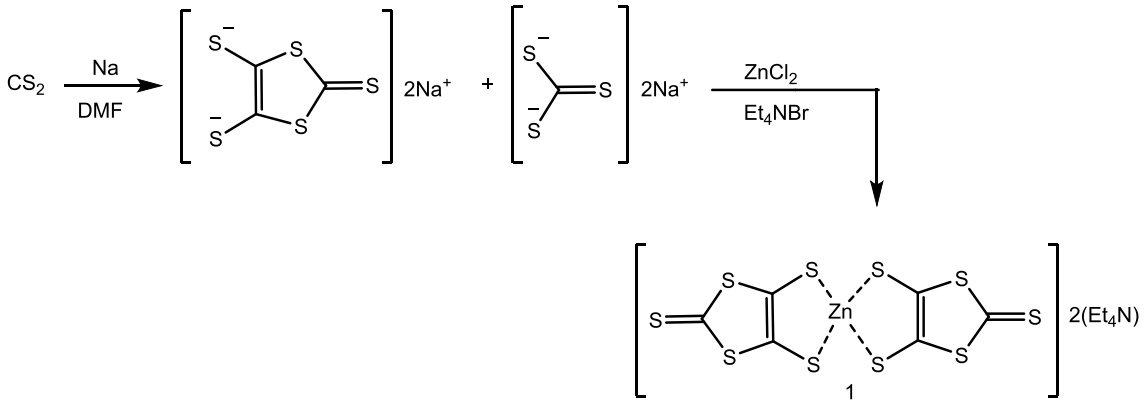


Figure 2. Preparation of tetraethylammonium bis(1,3-dithiole-2-thione-4,5-dithiol) zincate

The tetraethylammonium salt of $[Zn(dmit)]^{2-}$ **1** can be oxidized with iodine at low temperatures to 1,3-dithiole-2,4,5-trithione **2**, that contains the ready-made skeleton of half the molecule of ET.

Trithione **2** offers the possibility of modifying this half of the molecule by the addition of various unsaturated compounds by pericyclic reactions. The Diels-Alder reaction type was reported, for first time, by Neilands et al.[11] and have been applied to the

synthesis of a number of such thiones. Functionalized thiones, can subsequently exchange thione sulfur for oxygen using mercuric acetate giving oxo compounds.

The assembly of the ET molecule from the thione or the corresponding oxo compounds involves the coupling of 1,3-chalcogenones utilizing phosphines or phosphites, as shown in Figure 3.[9] Considering that the R_1 and R_2 substituents are 1,3-disulfides the basic structure of the ET is assembled.

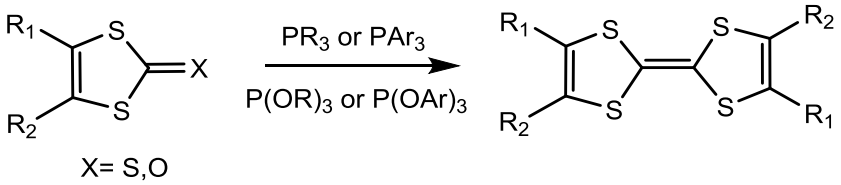


Figure 3. Assembly utilizing phosphines or phosphites

The attachment of the ET units with the aim of forming molecules with more than one unit can be achieved using different types of reactions considering that a large amount of functionalized ETs have been reported.

A versatile ET functionalized molecule is the hydroxymethyl-ET (HMET)[12,13]. The alcohol functional group allow through esterification with carboxylic acids or their derivatives the attachment to metal binding groups or to cores with more than one acid group.

3. AIMS

- Preparation of molecular systems containing more than one BEDT-TTF compound using established reactions. The first target compound is the HMET ester of the isonicotinic acid with the pyridine moiety as a metal binding group. By coordination of two or more pyridyl groups to a metal centre, M^{n+} systems with several donors might be prepared.

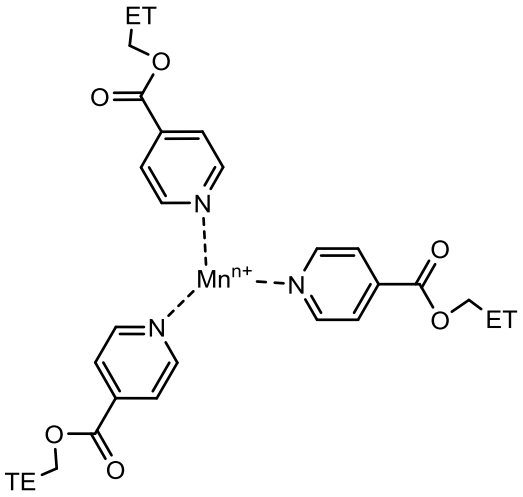


Figure 4. Target compound with a metal core and three ligands

- The second aim is the synthesis of BEDT-TTF donors with three-fold symmetry. The target compound is the HMET triester of trimesic acid.

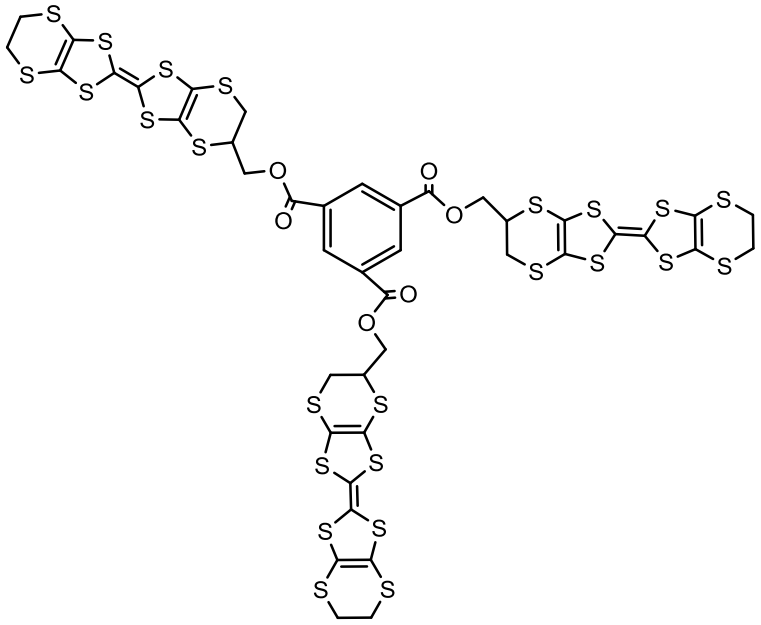


Figure 5. Target compound HMET triester of trimesic acid, **16**

4. METHODS AND TECHNIQUES IMPLEMENTED IN THE LABORATORY

In this section are described all the methods and techniques implemented in the laboratory for the synthesis of the different target compounds. A brief description of the theoretical basis and the reason for their use.

4.1 Reaction techniques

The reaction techniques used in this work are described.

4.1.1. Agitation

An efficient mixing of the reactants is often critical for the success of the reaction.[14] Thus, all the reactions in this work were carried out stirring with magnetic stirrers with Teflon-coated stirring bars.

4.1.2. Schlenk line

Schlenk line is a tubular glass apparatus used to perform air-free benchtop chemical manipulations. Air-free work is required when reagents or products are sensitive to oxidation. The dual manifold is the main body of the Schlenk line, as shown in Figure 6. It has two parallel glass tubes; one connected to the N_2 supply and the other to the vacuum. Taps allow switching between the gas and the vacuum lines and the six taps allow multiple reactions to be performed simultaneously.

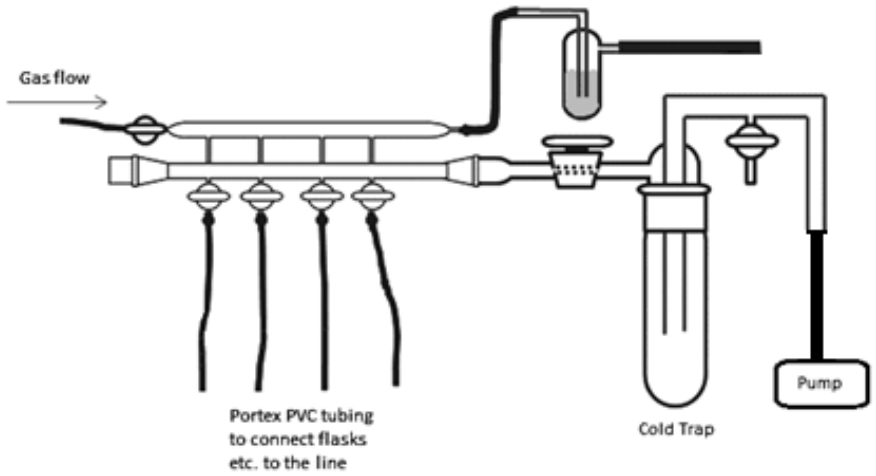


Figure 6. Complete Schlenck line set-up

The general procedure of degassing applied in this work, when the reaction takes place under N_2, consists on alternate vacuum/N_2 flow for five times. Special attention must be taken when the vacuum is applied due to the possible evaporation of the solvent under these pressure conditions.

4.1.3. Reflux

The main feature of the reflux reaction system allows, by choosing a solvent that boils at the desired reaction temperature and by running the reaction in the refluxing solvent, provide a built-in thermostat.[15]

The advantage of using this system is that it can be left for a long period of time at a constant temperature, without adding more solvent. There are different types of condensers, commonly a dimroth condenser was used in the reactions of this project.

4.2 Isolation techniques

Reaction workup usually requires more time than the actual running of the reaction and is the most frequent problem encountered in this work. In many reactions several isolation techniques were used for the successful purification of the desired product.

4.2.1. Filtration

The filtration is commonly used to separate two phases in a mixture reaction. One of them a solid and other a liquid. Depends which phase want to be collected it is done with two different type of filtration.

The gravity filtration is used when the solid has to be discarded and not used for subsequent reactions. The preparation includes a filtration funnel and filter paper.

The Büchner filtration is used when the solid needs to be insolated from the mixture reaction. It is done in a fritted glass filter and a conical Büchner, under reduced pressure connected to a pump vacuum.

In this work, all the filtrations were done using Buchner filtration because allows to dry the solid and collect all the solution. The only filtrations done using gravity filtration were those that allow to separate hydrated Na_2SO_4 or $MgSO_4$ of organic solutions.

4.2.2. Rotary evaporation

Rotary evaporation is commonly used in this work to remove volatile solvents from a non-volatile sample. It works reducing the pressure and increasing the rate evaporation of the solvent. Also a bath of warm water helps with the evaporation. Furthermore it has the possibility to rotate the flask forming a thin film with a greatly increased surface area, helping to prevent sudden boiling and a progressive evaporation of the solvent.[16]

All the evaporations were done using Buchi Rotavapor R-210. In one case, a different type of evaporation was done using a Buchi Glass Oven B-585 that allows the complete removal of solvents with higher boiling point like $P(OMe)_3$.

4.2.3. Liquid-liquid extraction

Extraction is a rapid and versatile technique that is usually used in this work to achieve a preliminary separation prior to a final purification step, mostly a chromatographic column. It is based on the relative solubilities of the compounds in two different immiscible solvents both in liquid phase. Inorganic salts generally prefer the aqueous phase, whereas most organics dissolve more readily in the organic phase.[17]

This technique is mostly used in this work as a washing procedure when the organic phase is treated with an acid or basic aqueous solution. When the organic compound that has to be separated is a carboxylic acid or an amine, the organic layer is treated with a saturated $NaHCO_3$ solution or with HCl solution, respectively.

4.2.4. Drying agents

As explained in previous section, most organic separations involve extractions from an aqueous solution and usually a small amount of water remains in the organic layer dissolved in the extraction solvent. Even in some cases, the physical separation of the layers in the extraction process may be incomplete. As a result, the organic layer usually needs to be dried with an anhydrous drying agent before recovering an organic product. Anhydrous drying agents like $MgSO_4$ or Na_2SO_4 react with water to form crystalline hydrates, which are insoluble in the organic phase and can be removed by gravity filtration.[17]

4.2.5. Chromatography column

Chromatography is used to separate mixtures of substances into their components. The method of separation in chromatography is based on the distribution of the components in a mixture between a fixed (stationary) and a moving (mobile) phase. In column chromatography, the stationary phase is a column of adsorbent through which the mobile phase moves on. The rate at which the components of a mixture are separated depends on the activity of the adsorbent and polarity of the solvent. Solvent systems for use as mobile phases can be determined from previous TLC experiments, the literature, or experimentally.

In this work, the stationary phase used was SilicaGel 60Å (40-63 micron), from Fluorochem Ltd and the sizes of the column were chosen depending on the retention factor of the compounds and the amount of desired product that need to be purified. The three different sizes used were a 4cm(ϕ) x 32cm as a standard size, a 4cm(ϕ) x 46cm as a large column, and a 3cm(ϕ) x 30cm as a small column. Furthermore, pressure with a pump was applied to the column for a faster elution speed and special attention is taken due to the possibility of overpressure in the column.

4.2.6. Thin Layer Chromatography (TLC)

Thin layer chromatography is applied to the "thin layer" versions of the column techniques described in previous section. Thin layer chromatography is a generally technique used to follow the reactions, to see how many compounds are present in the reaction mixture and helps to choose the solvent in the purification by column chromatography. The basis of the technique is the same as in the column chromatography, but the stationary phase is a thin, uniform layer of silica gel.

In most cases, the compounds prepared are UV active and a spot appears when the TLC plate is exposed to UV light. Circling these spots gently with a pencil permit an initial method for visualization. In other cases, developers like diluted solutions of phosphomolybdic acid (PMA) or ninhydrin were used for stain the TLC plates.

The stationary phase for TLC plates used in this work was silica gel coated on glass plates and they were acquired from Merck Company (TLC Silica gel 60 F_{254} 2.5x7.5cm).

4.3 Structure determination techniques

4.3.1. Elemental Analysis (EA)

Elemental analysis is the process for determining the partial or complete chemical formula for a substance. Most commonly, it involves the complete combustion in air or oxygen of the substance and then quantifying the amount of elemental oxides and nitrogen produced. The determination of the mass percentage of CHN elements in the sample is based upon the direct weight of the material sampled. Therefore, it is very important that samples are dry, free of foreign substances such as dust, parafilm, and paper filter fibers.

The results of an elemental analysis for carbon, hydrogen and nitrogen have traditionally been regarded as acceptable, if the accuracy of the results is within 0.3% of the theoretical value.[18]

The chemical analysis data were obtained from the Science Centre, London Metropolitan University.

4.3.2. Nuclear Magnetic Resonance (^{1}H NMR, ^{13}C NMR)

Nuclear Magnetic Resonance spectroscopy is one of the most important modern instrumental techniques used in the determination of molecular structure. Using radio waves in the presence of a strong magnetic field is the basis for the operation of this technique. Some atomic nuclei like ^{1}H and ^{13}C have a nuclear spin(I), and the presence of a spin makes these nuclei behave rather like bar magnets when a strong magnetic field is applied, when a radio frequency signal is applied to the system.

This technique provides information about the structure of the compound and allow the evaluation of the presence of impurities. In some cases, after the analysis of the

spectrum obtained, additional purification steps were performed to increase the purity of the product obtained.

The characterization of the molecular structure of most of the compounds obtained was made by NMR ^{1}H and ^{13}C using a JEOL Delta2 Nuclear Magnetic Resonance spectrometer (400 MHz). Furthermore, all the ^{13}C NMR spectra were run using the advance mode of the sofware increasing the number of scans with the aim of increasing the relation signal/noise. Without this change, it is difficult to observe the peaks corresponding to quaternary carbons, which have weaker signals.

4.3.3. Infrared Spectroscopy (IR)

The infrared region of the electromagnetic spectrum provides quick and valuable information. The infrared light imposed on a molecule contains enough energy to interact with the molecule causing vibrational and rotational changes. These changes can be processed and the data obtained allow the identification of characteristic absorption bands. The positions of these IR absorption bands have been correlated with types of chemical bonds, which can provide key information about the nature of functional groups in the sample.

In this work, IR spectra were collected only for the data acquisition of the final compounds of the reaction scheme using a Perkin Elmer Instrument (FT-IR).

4.3.4. Melting point (mp)

The melting point of a compound is useful in establishing its identity and as a criterion of its purity. Since the melting point of a solid can be easily and accurately determined with small amounts of material, it is the physical property that has most often been used in this work, for the identification and characterization of solids.

The determination of the melting point was carried out in a Stuart SMP30 instrument.

4.3.5. Mass Spectra (MS)

The mass spectrometry involves energy transfer from energetic electrons. This energy causes ionization of the molecules, and the analyser measures the masses of these ions as a relation mass/charge (m/z). Fragmentation of the initially formed ions provides additional information. Therefore, mass spectrometry is used to determine the molecular weights and molecular formulas of compounds.

The MS in this work were carried out at the EPSRC National Mass Spectrometry Service in Swansea University, where a variety of ionisation modes is available.

4.4 Crystallization techniques

Two different crystallization techniques were carried out for the synthesis of metal complexes. The first technique consists of mixing two solutions, one containing the donor **8** and the other containing metal salts and left the reaction stirring for hours.

The other technique involve a liquid-liquid diffusion. The liquid-liquid diffusions relies on the fact that solvents of substantially different densities mix remarkably slowly when they are not stirred. The procedure consists of dissolving the donor **8** in the more dense solvent and then adding a top layer of the less dense solvent containing the metal salt. If this system is not stirred, shaken, or vibrated too much it take several minutes or hours for the two layers to mix. The resulting slow diffusion of solvents across the boundary layer often results in crystals growing there.

5. EXPERIMENTAL PART

All the techniques and instruments used in the experimentation are described in previous section: METHODS AND TECHNIQUES IMPLEMENTED IN THE LABORATORY.

All the reactions carried out in this project were supervised by Professor John Wallis or in his absence by his research assistant Dr Songjie Yang. The risk assessment COSHH forms were prepared according to Human Resources regulations.

5.1 Reagents and solvents

In these list are collected all reagents (Table 1) and solvents (Table 2) used in the experimental part with their handling and hazards in the ANNEX.

Table 1. Solvents with their purity and the company where they were purchased. In parentheses the abbreviation used in this work

Solvents	
Acetone, 99.5 % Fisher	Dimethyl sulfoxide (DMSO), 99.9% Fisher
Acetonitrile (CH_3CN), 99.5% Fisher	Ethanol (EtOH), 99.5% Fisher
Chloroform ($CHCl_3$), 99.8% Fisher	Ethyl acetate (EtOAc), 99.9% Fisher
Cyclohexane, 99% Fisher	Hexane, 95% Fisher
Dichloromethane (DCM), 99% Fisher	Methanol (MeOH), 99.8% Fisher
Diethyl Ether (Et_2O), 99% Fisher	Toluene, 99.5% Fisher
Dimethylformamide (DMF), 99% Fisher	Tetrahydrofuran (THF), 99.5% Fisher

Table 2. Reagents with their purity and the company where they were purchased. In parentheses the abbreviation used in this work.

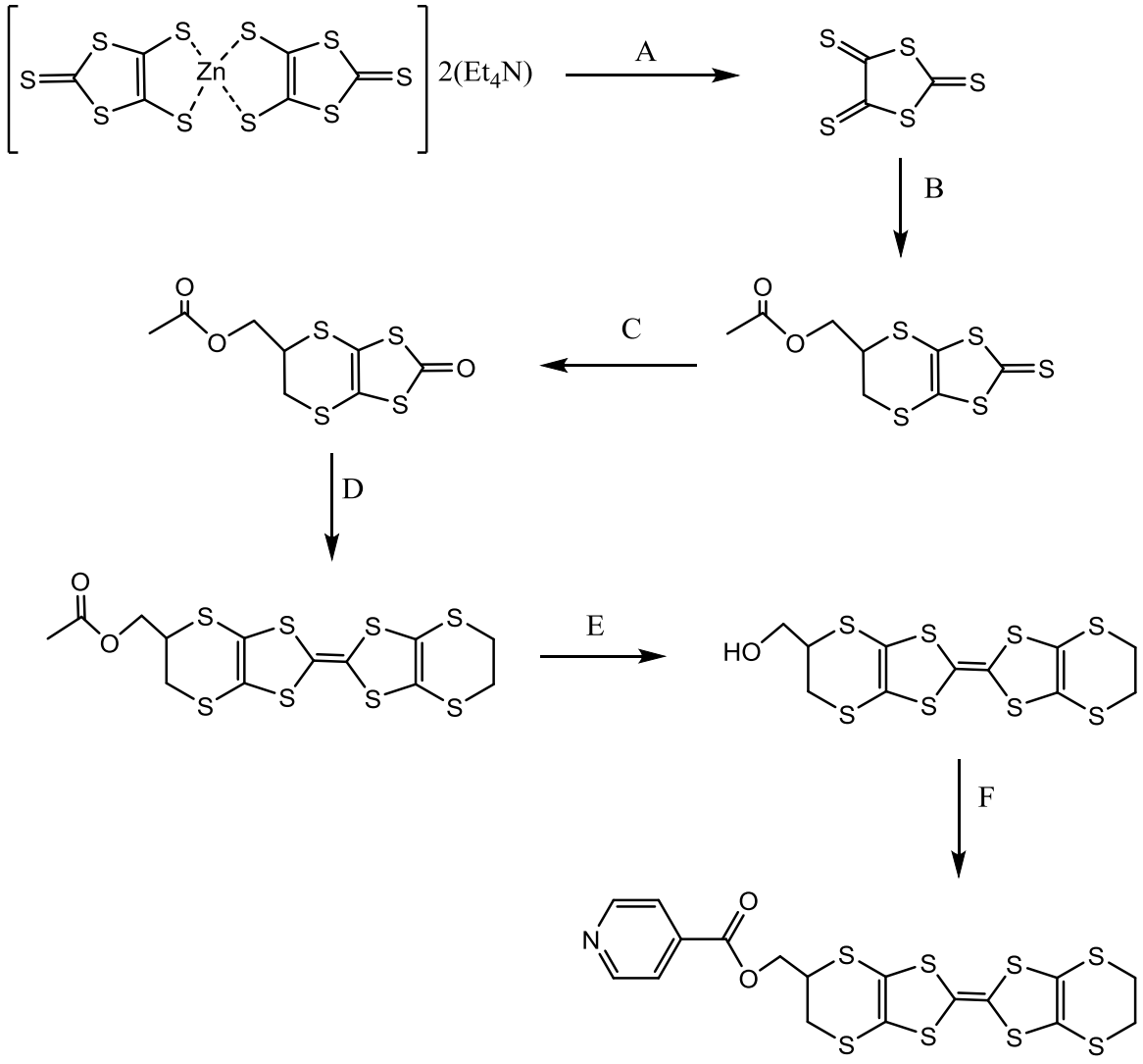
Reagents	
1,2-Dibromoethane, 99% Aldrich	Carbon disulfide (CS_2), 99.9% Alfa Aesar
Allyl acetate, 99% Sigma-Aldrich	Mercuric Acetate ($Hg(OAc)_2$), 98% BDH Laboratory Reagents
Allyl alcohol, 99% Aldrich	Trimethyl phosphite ($P(OMe)_3$), 97% Sigma-Aldrich
Copper (II) chloride (CuCl), 97% Sigma-Aldrich	4-Dimethylaminopyridine (DMAP), 99% Acros Organics
Copper (II) trifluoromethanesulfonate, 98% Aldrich	1-(3-Dimethylaminopropyl)-3-ethylcarbodiimide hydrochloride (EDC), 98% Alfa Aesar
Hydrochloric acid (HCl) 36.5% v/v Fisher	Thionyl chloride ($SOCl_2$), 97% Sigma-Aldrich
Isonicotinic acid, 99% Aldrich	Zinc (II) trifluoromethanesulfonate, 98% Alfa Aesar
N,N'-Dicyclohexylcarbodiimide (DCC), 99% Acros Organics	Iodine (I_2), 99.99% Sigma-Aldrich

Pyridine, 99% Sigma-Aldrich	Manganese (II) trifluoromethane sulfonate, 98% Aldrich
Sodium hydrogen carbonate ($NaHCO_3$), 99.7% Fisher	Sodium chloride (NaCl), 99% Fisher
Trimesic acid, 95% Aldrich	Sodium sulphate anhydrous (Na_2SO_4), 99% Fisher

5.2 Synthesis

5.2.1. Synthesis of the HMET ester of isonicotinic acid, 8[13]

The general scheme of the synthesis of the HMET ester of isonicotinic acid, is shown in Scheme 1. The preparation of the starting material for this synthesis is shown in Figure 2.



Scheme 1. General route for the preparation of the HMET ester of isonicotinic acid

5.2.1.1. Reaction A. Preparation of 1,3-Dithiolane-2,4,5-trithione, 2

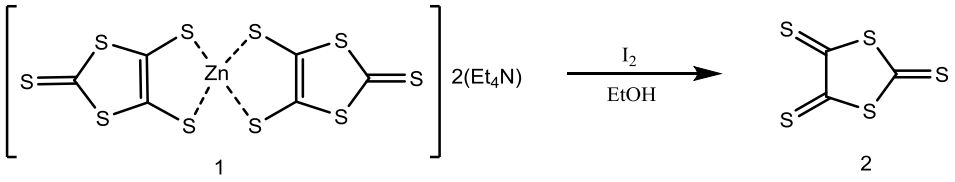


Figure 7. Preparation of 1,3-Dithiolane-2,4,5-trithione, **2**

In a 250ml conical flask was dissolved the tetraethylammonium salt of $[Zn(dmit)]^{2-}$ **1** (15.10g, 21mmol) in acetone (130ml). The solution was filtered and added to a 1L three neck flask in a Dewar located over a magnetic stirrer. The solution was cooled to -78ºC in a CO_2 solid/acetone bath. The solid CO_2 (dry ice) was added slowly to the acetone due to the high amount of gas generated. In a 500ml beaker was dissolved I_2 (10.90g, 83.91mmol) in EtOH (300ml). The iodine solution was added dropwise over 1.5h with a dropping funnel and the yellow mustard suspension formed was left stirring overnight. The yellow mustard solid was isolated by filtration in a fritted glass filter and washed with acetone (2x50ml), water (2x50ml), EtOH (2x50ml), and Et_2O (3x50ml) and left to dry on a watch glass. The product **2** was weighed affording (9.64g, 117%). The yield corresponds to >100% due to a presence of impurities such as ZnI_2. No available ^{1}H or ^{13}C NMR due to high insolubility.

5.2.1.2. Reaction B. Preparation of 5-Acetyloxymethyl-5,6-dihydro-[1,3]dithiolo [4,5-b][1,4]dithiin-2-thione, 3

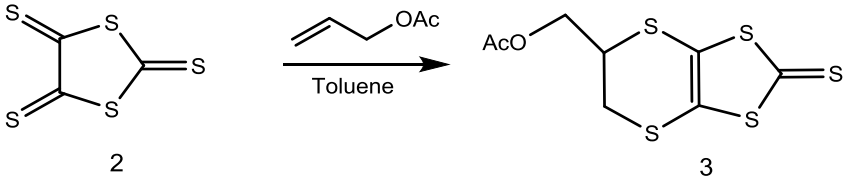


Figure 8. Preparation of 5-Acetyloxymethyl-5,6-dihydro-[1,3]dithiolo[4,5-b][1,4]dithiin-2-thione, **3**

In a 250ml three neck flask was suspended trithione **2** (4.97g, 25.30mmol) and allyl acetate (4.41ml, 41.00mmol) in toluene (100ml). The suspension was heated to reflux at 130ºC for 20h under N_2. After 30min the reaction mixture becomes darker. The solvent was evaporated in the rotavap and the dark oil purified by chromatography on silica gel eluting with DCM. The dark oil was applied directly to the column without dispersion in silica gel. A second chromatographic column was required for a total purification of the product, eluting with cyclohexane 1:1 EtOAc. The fraction containing thione **3** was evaporated in the rotavap and dried in *vacuo* to give product **3** (2.02g, 27%) as a red oil. ^{1}H NMR(400MHz, $CDCl_3$) δ ppm: 4.36 (2H, d, J=7.9Hz), 3.96 (1H, m), 3.37 (1H, dd, J=13.2Hz, 3.9Hz), 3.32 (1H, dd, J=13.2Hz, 5.3Hz), 2.10 (3H, s). No available ^{13}C NMR.

5.2.1.3. Reaction C. Preparation of 5-Acetyloxymethyl-5,6-dihydro-[1,3]dithiolo-[4,5-b][1,4]dithiin-2-one, 4

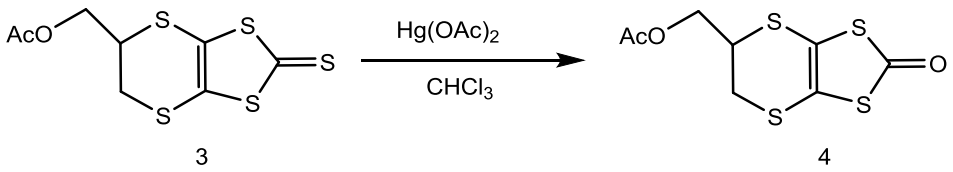


Figure 9. Preparation of 5-Acetyloxymethyl-5,6-dihydro-[1,3]dithiolo-[4,5-b][1,4]dithiin-2-one, **4**

In a 100ml round-bottom flask was dissolved thione **3** (2.02g, 6.83mmol) in $CHCl_3$ (30ml) and mercuric acetate (3.27g, 10.25mmol) was added. A white precipitate could be seen to form almost immediately. The mixture was stirred for 2h, filtered and the solid residue washed with $CHCl_3$. The combined filtrates were collected and washed with a solution of sodium chloride in water. Drying over anhydrous $MgSO_4$ and concentration in a rotavap and drying in *vacuo* gave product **4** (1.75g, 90%) as an orange solid. No available ^{1}H or ^{13}C NMR.

5.2.1.4. Reaction Da. Preparation of 5,6-dihydro-1,3-dithiolo[4,5-b][1,4]dithiin-2-thione, 5

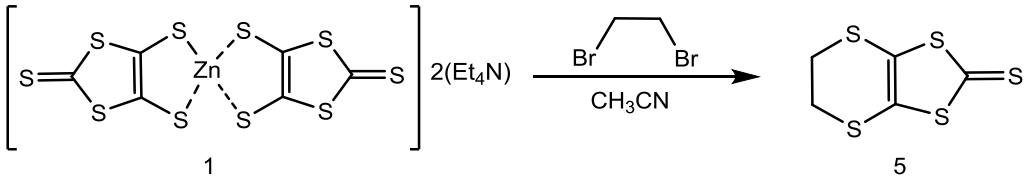


Figure 10. Preparation of unsubstituted thione **5** (5,6-dihydro-1,3-dithiolo[4,5-b][1,4]dithiin-2-thione).

In a 250ml round-bottom flask was dissolved Zn complex **1** (20.00g, 27.83mmol) in CH_3CN (120ml). 1,2-Dibromoethane (5ml, 58.00mmol) was added and the mixture was heated to reflux at 85ºC overnight under N_2. The mixture was cooled and the dark yellow solid formed collected by filtration and washed with cooled MeOH (3x30ml). The solid was dissolved in CH_2Cl_2 and decolourised with active charcoal while heating to boiling for 20min. The decolouring procedure was repeated three times until the liquid phase after filtrate was slightly yellow. Removal of solvent yielded unsubstituted thione **5** (11.50g, 92%) as a gold yellow solid. ^{1}H NMR (400MHz, $CDCl_3$) δ ppm: 3.40 (4H, s). ^{13}C NMR (100 MHz, $CDCl_3$) δ ppm: 29.70 (CH_2-CH_2), 122.89 (C=C), 207.98 (C=S).

5.2.1.5. Reaction Db. Preparation of Acetyloxymethyl-ET, 6

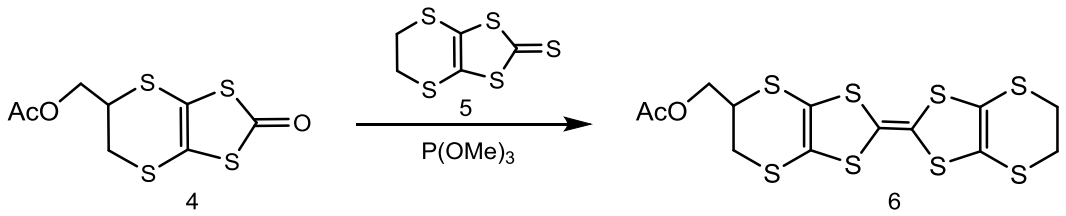


Figure 11. Preparation of Acetyloxymethyl-ET, **6**

In a 100ml round-bottom flask, oxo compound **4** (1.73g, 6.17mmol) and unsubstituted thione **5** were dissolved in trimethyl phosphite (30ml). The mixture was heated under reflux for 24h at 75ºC under N_2 to give a dark orange solution. A few amount of dark solid was also formed. The solution was filtered and the filtrates were collected separately. The solid was washed with $CHCl_3$ and the filtrates collected. The solution containing trimethyl phosphite was evaporated in the rotavap and the remaining solid was dissolved in $CHCl_3$ and mixed with the filtrates. The resulting orange solution was evaporated with 10g of silica gel. A chromatographic column was performed eluting with cyclohexane 5:1 EtOAc. Due to the difficult separation of homocoupling products a second chromatographic column eluting with cyclohexane 5:1 EtOAc was required. Removal of solvent yielded accetyloxymethyl-ET **6** (1.06g, 38%) as an orange solid. No available ^{1}H or ^{13}C NMR.

5.2.1.6. Reaction E. Preparation of Hydroxymethyl-ET, 7

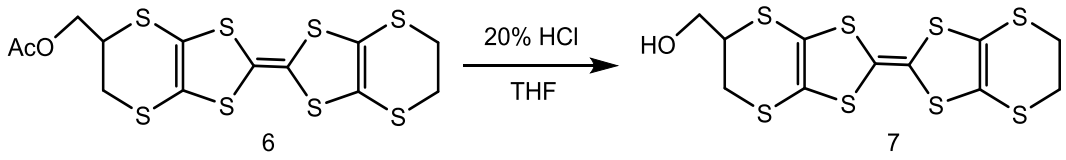


Figure 12. Preparation of Hydroxymethyl-ET, **7**

In a 100ml round-bottom flask was dissolved the acetyloxymethyl-ET **6** (0.50g, 1.08 mmol) in THF (20ml). A 20% HCl solution (10ml) was prepared mixing HCl 37% (4.5ml) and water (5.5ml). The aqueous solution was added to the organic solution and stirred under N_2 for 21h. The previous orange solution becomes darker when the reaction was finished. The solution was neutralised by the addition of solid $NaHCO_3$. When the solution stops bubbling the solution was already neutralized and two layers were observed. The organic layer was diluted with THF (20ml) and the upper organic layer was collected and dried over Na_2SO_4. Removal of solvent yielded donor **7** (0.45g, 99%) as an orange solid. No available ^{1}H or ^{13}C NMR.

5.2.1.7. Reaction F. Preparation of HMET ester of isonicotinic acid, 8

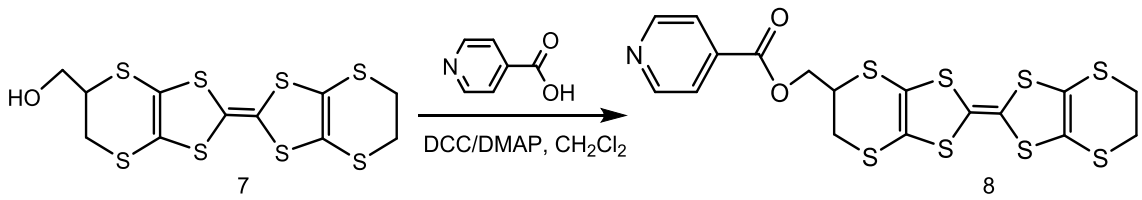
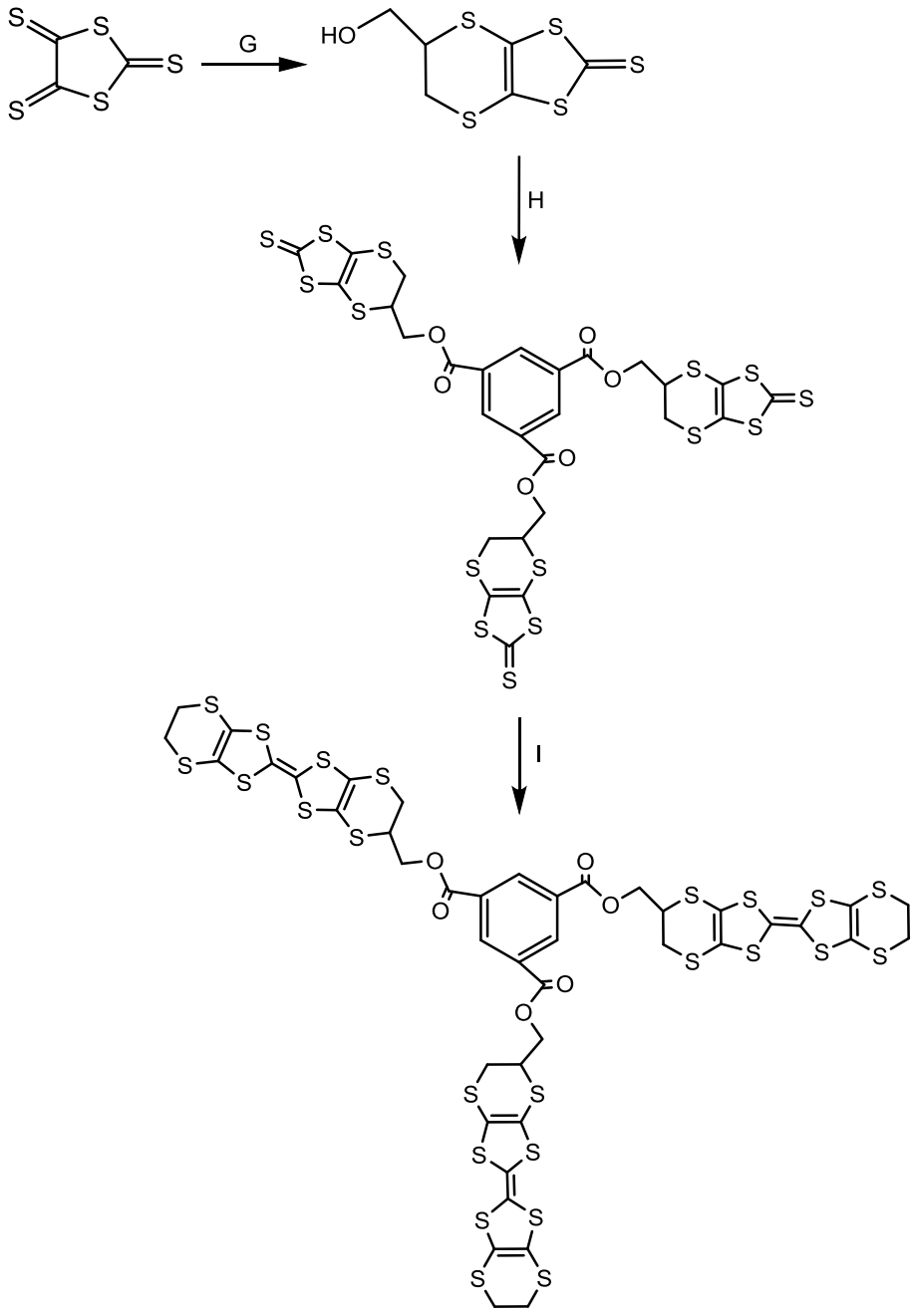


Figure 13. Preparation of HMET ester of isonicotinic acid, **8**

In a 100ml round-bottom flask was dissolved HMET **7** (0.67g, 1.62mmol), isonicotinic acid (0.26g, 2.10mmol) and DMAP (15mg, 0.12mmol) in dry CH_2Cl_2 (40ml). DCC (0.43g, 2.15mmol) was added and the mixture was stirred for 48h under N_2. The resulting orange solution was evaporated with 4g of silica gel. A chromatographic column was performed eluting with cyclohexane 5:1 EtOAc. A large amount of side products were eluted and an orange zone appears in the top of the column. The polarity of the eluting solvent was increased first with cyclohexane 3:1 EtOAc and ending with cyclohexane 2:1 EtOAc. The product was not enough pure. The impure donor **8** was stirred 48h in pure hexane and filtered. An additional chromatographic column was required for the total purification of the donor **8**, eluting DCM 2:1 EtOAc. The fraction corresponding to pure donor **8** was collected. Removal of solvent yielded donor **8** (0.36g, 43%) as an orange solid. ^{1}H NMR (400MHz, $CDCl_3$) δ ppm: 3.30 (6H, m,3x(-CH_2-)), 4.04 (1H,m, CH-CH_2O), 4.60 (2H, m, CH_2O), 7.83 (2H, d, *J*=5.72 Hz, CH=C), 8.80 (2H, d,J=7.65Hz), CH=N). ^{13}C NMR (100 MHz, $CDCl_3$) δ ppm 30.24 (CH_2-CH_2), 32.24 (CH_2-CH) 41.86 (CH-$CH_2$0) 65.85 (CH_2O) 113.83, 113.89, 114.07 (sp^2-C) 122.95,(Py. ring) 136.57 (o-COOH) 150.89 (Py. ring) 164.67 (C=O).

5.2.2. Synthesis of HMET triester of trimesic acid, 16

The general scheme of the synthesis of HMET triester of trimesic acid is shown in Scheme 2.



Scheme 2. General scheme of preparation of triester ET of trimesic acid.

5.2.2.1. Reaction G. Preparation of 5,6-Dihydro-5-(hydroxymethyl)-1,3-dithiolo-[4,5-b]-1,4-dithiin-2-thione, 9

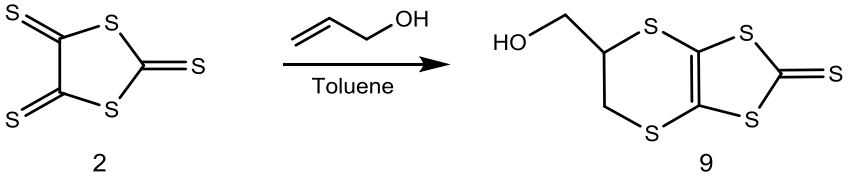


Figure 14. Preparation of 5,6-Dihydro-5-(hydroxymethyl)-1,3-dithiolo-[4,5-b]-1,4-dithiin-2-thione, **9**

In a 250ml three neck flask was suspended trithione **2** (7.50, 25.30mmol) and allyl acetate (4.42ml, 65.00mmol) in toluene (150ml). The suspension was heated to reflux at 130ºC for 20h under N_2. After 30min the reaction mixture becomes darker. The resulting dark brown solution was evaporated with 20g of silica gel. A chromatographic column eluting with cyclohexane 1:1 EtOAc was required. The fraction containing thione **9** was evaporated in the rotavap and dried in *vacuo* to give product **9** (5.37g, 55%) as a brown solid. ^{1}H NMR(400MHz, $CDCl_3$) δ ppm: 3.96 (1H, m, OH), 3.85 (2H, m, CH_2O), 3.37 (2H, m, -CH_2-). No available ^{13}C NMR.

5.2.2.2. Reaction Ha. Preparation of 1,3,5-benzenetricarbonyl trichloride, 11[19]

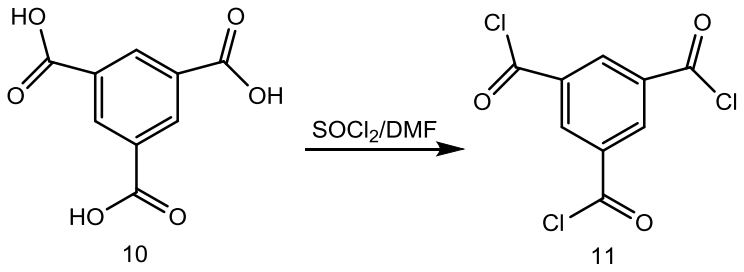


Figure 15. Preparation of 1,3,5-benzenetricarbonyl trichloride, **11**

A 100ml round-bottom flask was charged with trimesic acid **10** (2.00g, 9.5mmol) and suspended in thionyl chloride (6ml)/DMF (0.05ml). The mixture was heated under reflux for 3.5h at 80ºC under N_2. After a while, the reaction mixture acquired a faintly yellow colour. The solution was concentrated in a rotary evaporator and dissolved in DCM (20ml). The solution was concentrated again but after 20min there was still liquid. The solution was cooled in an ice bath and the dense liquid solidified, to give **11** (2.52g, 99%) as a faintly yellow solid. ^{1}H NMR (400MHz, $CDCl_3$) δ: 9.06 (3H, s). ^{13}C NMR (100MHz, $CDCl_3$) δ: 166.15 (-COCl), 138.16 (Ph-H), 135.54 (Ph-COCl).

5.2.2.3 Reaction Hb. Preparation of triester thione, 12[20,21]

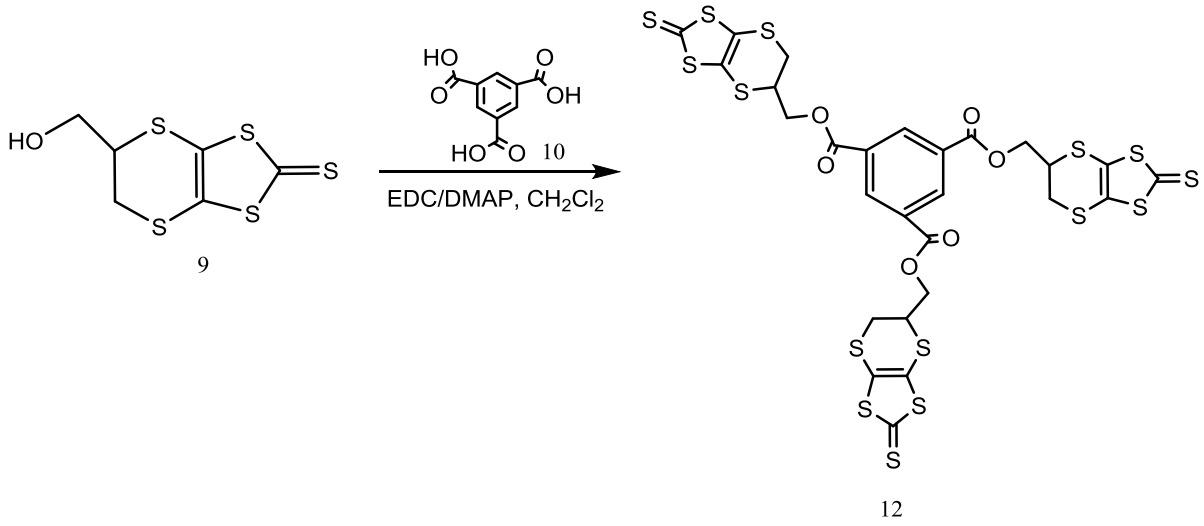


Figure 16. Preparation of triester thione, **12** using the coupling agent EDC

In a 100ml round-bottom flask a mixture of hydroxymethyl-thione **9** (0.50g, 1.96mmol) and trimesic acid **10** (0.13g, 0.60mmol) were dried for 30min in vacuo. A CH_2Cl_2 solution (65ml) containing EDC (1.40g, 9.00mmol) and DMAP (0.36g, 3.00mmol) was added. The reaction proceed stirring 19h at room temperature. After 19h, a TLC plate eluting with THF 4:1 cyclohexane confirms that there was no alcohol remaining in the reaction mixture and one equivalent of hydroxymethyl-thione **9** (0.15g, 0.60mmol) was added. The reaction mixture was left stirring 24h. The solution was treated with 0.5M HCl (2x50ml) and with saturated $NaHCO_3$ (2x50ml). The organic layer was dried over Na_2SO_4 and the solvent evaporated with 5g of silica-gel. The product **12** was purified by chromatography eluting with THF 4:1 cyclohexane using a large column due to the difficulty of separation the triester thione **12** from hydroxymethyl-thione **9**. The fraction containing triester thione **12** was collected. Removal of solvent yielded the product **12** (0.54g, 98%) as a yellow solid. ^{1}H NMR (400MHz, $CDCl_3$) δ ppm: 3.36 (6H, m, -CH_2-), 4.17 (3H, m, CH-CH_2O), 4.71 (6H, m, CH_2O), 8.84 (3H, s, CH). No available ^{13}C NMR.

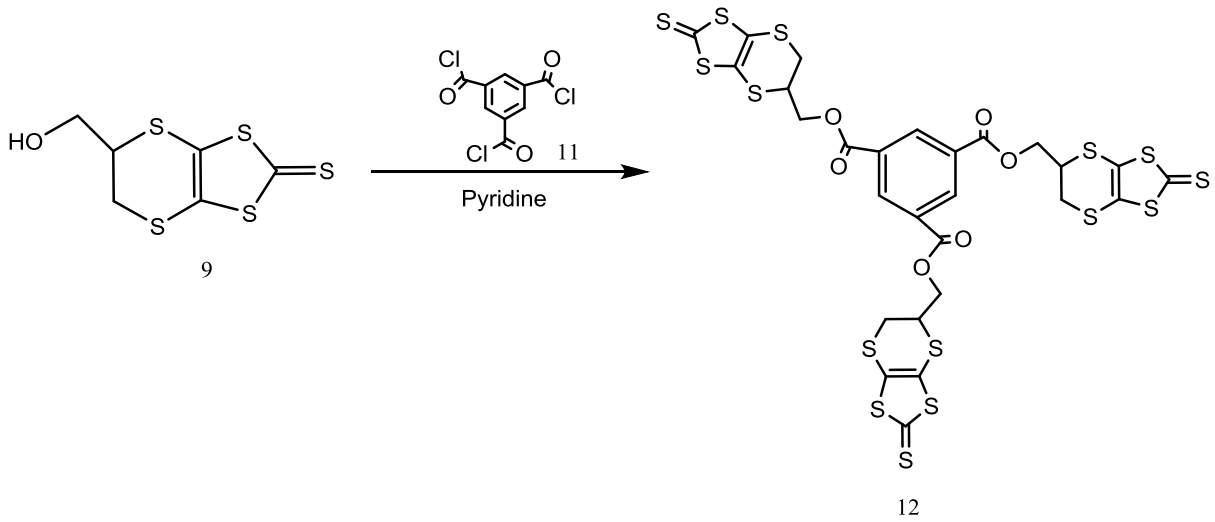


Figure 17. Preparation triester thione, **12** using 1,3,5-benzenecarbonyl trichloride

In a 100ml two neck flask the hydroxymethyl thione **9** was dissolved in pyridine (15ml). The solution was cooled to 0ºC in an ice bath. A solution containing 1,3,5-benzenetricarbonyl trichloride **11** (0.25g, 0.94mmol) in DCM (7.5ml) was slowly added with a syringue throught the septum for 30min. The dark solution was left stirring overnight under N_2. The reaction mixure was diluted with DCM (20ml) and treated with HCl 1M (3x30ml) and brine (30ml). The organic layer was dried over Na_2SO_4 and evaporated with 5g silica gel. The product **12** was purified by chromatography eluting with THF 4:1 cyclohexane using a large column due to the difficulty of separation the triester thione **12** to hydroxymethyl-thione **9**. A colourless impurity appears in the TLC eluting THF 4:1 cyclohexane at the same retention factor of the triester thione **12**. The fraction containing **12** and colourless impurity was collected and the solvent evaporated in the rotavap. A dark solid was collected and dissolved in DCM. A large amount of solid was not soluble in DCM even with hot DCM. The DCM solution was eluted with THF 4:1 cyclohexane in a TLC plate and the colourless impurity already disappeared. A large chromatographic column eluting THF 4:1 cyclohexane gives a fraction containing triester thione **12**. Removal of solvent yielded the product **12** (0.14g, 16%) as a yellow solid. No available ^{1}H NMR, ^{13}C NMR.

5.2.2.4 Reaction Hc. Preparation of triester oxo compound, 17

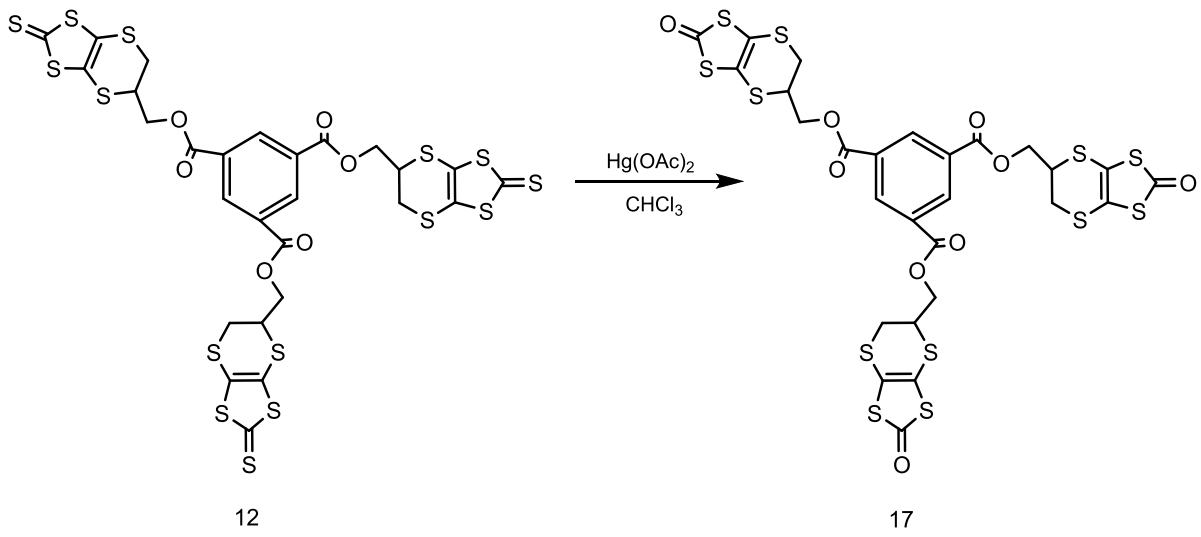


Figure 18. Preparation of triester oxocompound **17**

The solubility of **12** was too low for preparing the oxo compound **17** by oxidation with mercuric acetate.

5.2.2.5. Reaction Ia. Preparation of 4,5-Bis(methylthio)-1,3-dithiol-2-thione, 13

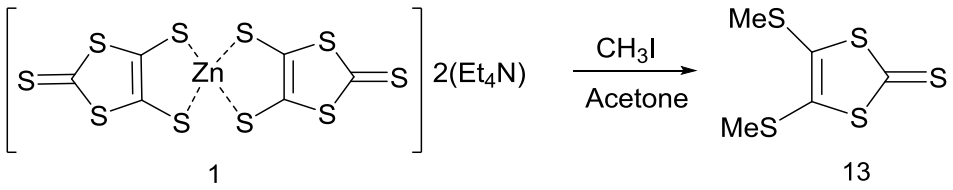


Figure 19. Preparation of 4,5-Bis(methylthio)-1,3-dithiol-2-thione, **13**

In a 100ml round-bottom flask was dissolved Zn complex **1** (5.29g, 7.36mmol) in acetone (50ml). The CH_3I (2.3ml, 29.45mmol) was added slowly and stirred overnight under N_2. A yellow mustard precipitate was seen to form after a few hours. The precipitate was filtrated and washed several times with $CHCl_3$. The filtrates were collected and washed with water (2x70ml). The organic layer was dried over $NaSO_4$. Removal of solvent yielded thione **13** (3.06g, 91%) as a dark yellow solid. ^{1}H NMR (400MHz, $CDCl_3$) δ ppm: 2.49 (6H, s). ^{13}C NMR (100 MHz, $CDCl_3$) δ ppm: 19.35 (CH_3-S), 136.00 (C=C), 211.01 (C=S)

5.2.2.6. Reaction Ib. Preparation of 4,5-Bis(methylthio)-1,3-dithiol ,14

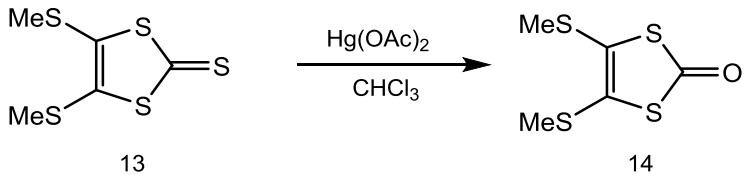


Figure 20. Preparation of 4,5-Bis(methylthio)-1,3-dithiol, **14**

In a 50ml round-bottom flask dimethyl thione **13** (1.2g, 5.30mmol) was dissolved in $CHCl_3$ (30ml). The solution was stirred until all the solid was totally dissolved acquiring a dark orange colour. Then, mercuric acetate (2.53g, 7.95mmol) was added. A white precipitate could be seen to form almost immediately. The mixture was stirred for 1.5h, filtered and the solid residue washed in $CHCl_3$ (3x20ml). The combined filtrates were collected and washed with a solution of NaCl in water (2x50ml). The organic layer was dried over Na_2SO_4. Removal of solvent yielded **14** (1.06g, 95%) as an orange solid. ^1H NMR (400MHz, $CDCl_3$) δ ppm: 2.45 (6H, s). ^{13}C NMR (100 MHz, $CDCl_3$) δ ppm: 19.38 (CH_3-S), 126.90 (C=C), 189.93 (C=O)

5.2.2.7. Reaction Ic. Preparation of Hydroxymethyl DMTEDT-TTF triester of trimesic acid, 15

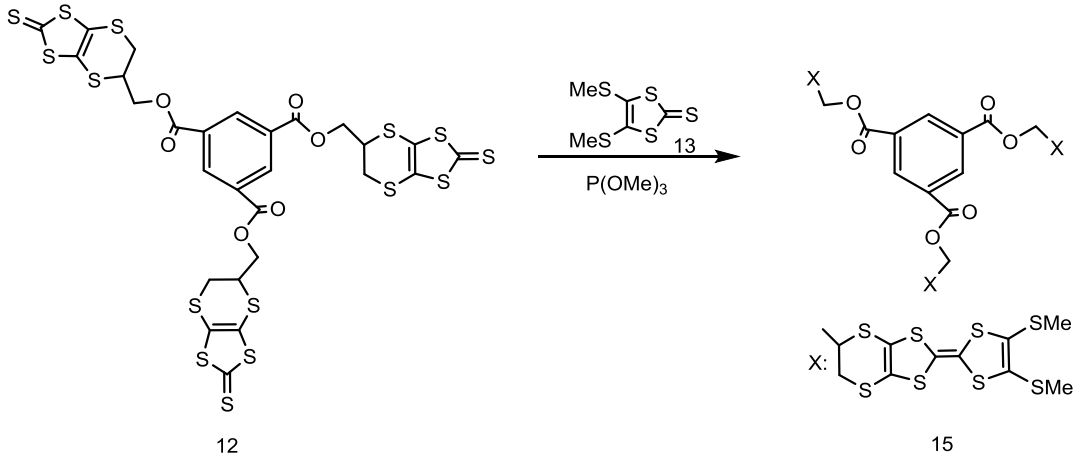


Figure 21. Preparation of Hydroxymethyl DMTEDT-TTF triester of trimesic acid, **15**

In a 50ml three neck flask triester thione **12** (0.10g, 0.11mmol) was dissolved in $P(OMe)_3$ (10ml). After 2 min. stirring, thione **13** (0.11g, 0.5mmol) was added and the mixture was stirred and heated at 80 °C overnight under N_2. After 30min, a solid dark ball was formed in the solution and the solution was slightly yellow coloured. After 20h, the reaction mixture was collected using a pipette and the remaining solids dissolved in $CHCl_3$ (150ml) under reflux for 2h. After the 2h refluxing, there was a green dark solid on the bottom of the flask. The yellow solution $CHCl_3$ was eluted with DCM

10:1 cyclohexane in a TLC plate and only starting material was observed. No evidence of desired product formed in the reaction.

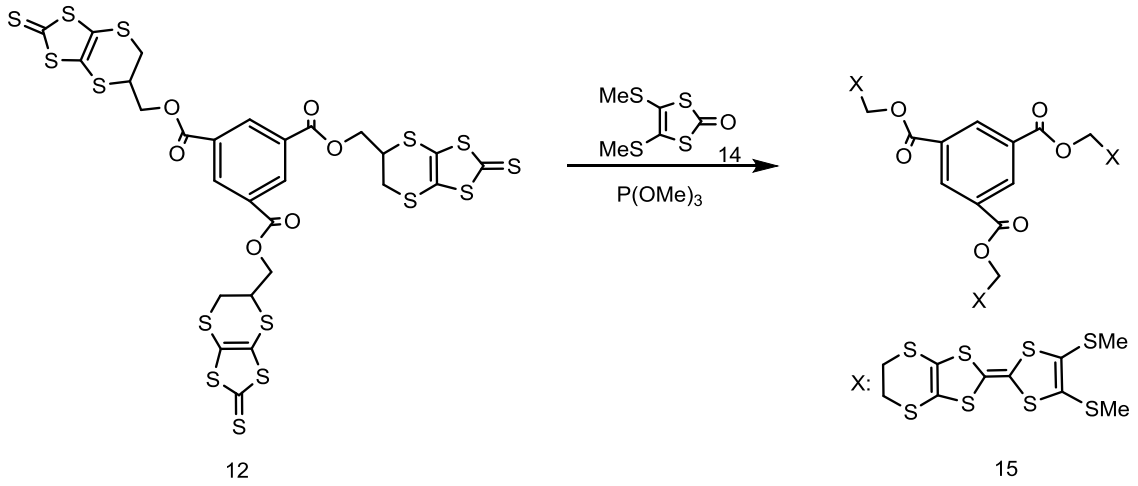


Figure 22. Preparation of Hydroxymethyl DMTEDT-TTF triester of trimesic acid, **15**

In a 50ml three neck flask triester thione **12** (0.10g, 0.10mmol) was dissolved in $P(OMe)_3$ (20ml). After 2 min. stirring the oxo compound **14** (0.13g, 0.6mmol) was added and the mixture was stirred and heated at 80 °C overnight under N_2. After 20h the reaction mixture was collected using a pipette and a small amount of dark red solid could be seen in the bottom of the flask. The solvent of the reaction mixture, orange coloured, was distilled and a orange oil was obtained. The orange oil becomes solid after a few hours. It was dissolved in DCM and evaporated in the rotavap with 4g silicagel. A small chromatographic column eluting with DCM 12:1 EtOAc allowed the collection of different fractions. The first fraction was collected (Fraction 1) then a second fraction was collected (Fraction 2). The polarity was increased until DCM 5:1 EtOAc and the third fraction was collected (Fraction 3). The column was washed with THF and another fraction was collected (Fraction 4). The different fractions were analysed by NMR spectroscopy. There was no evidence of desired product formed in the reaction.

5.2.2.8. Reaction Id. Preparation of HMET triester of trimesic acid, 16[20]

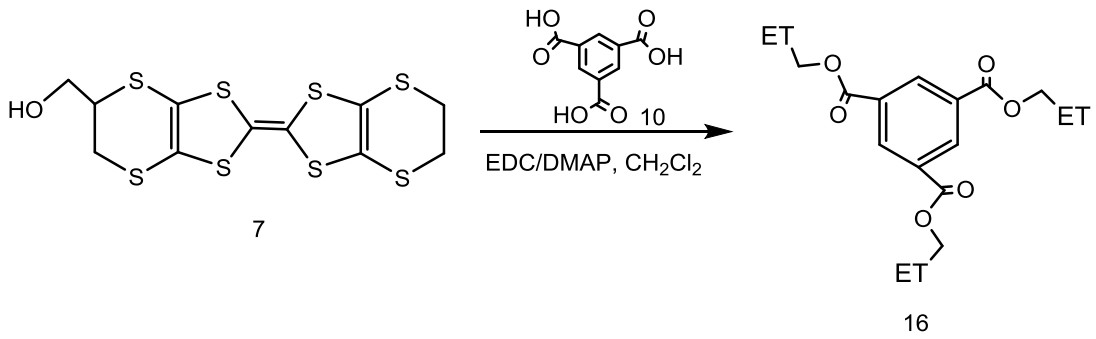


Figure 23. Preparation of HMET triester of trimesic acid, **16**

In a 50ml round-bottom flask a mixture of HMET **7** (0.118g, 0.284mmol) and trimesic acid 10 (15mg, 0.071mmol) was dried for 30min in vacuo. A CH_2Cl_2 solution (25ml) containing EDC (0.165g, 1.065mmol) and DMAP (45mg, 0.355mmol) was added. The reaction proceeded stirring 19h at room temperature. An orange suspension was formed and the reaction mixture was diluted with CH_2Cl_2 (120ml). The solution was treated with 0.5M HCl (2x50ml) and with saturated $NaHCO_3$ (2x50ml). The organic layer was dried over Na_2SO_4 and the solvent evaporated with 4g of silica-gel. A chromatographic column eluting with DCM 10:1 EtOAc was required. The first orange fraction was collected, and shows a single spot in the TLC plate. After removal of solvent yielded product **16** (10mg, 10%). According to ^1H NMR no total purification of desired compound was obtained.

5.3 HMET ester of Isonicotinic acid metal complexes[22]

5.3.1. Preparation of $CuCl_2$ complex

In a 50ml round-bottom flask donor **8** (52mg, 0.1mmol) was dissolved in hot DCM (5ml). A solution of $CuCl_2$ (27mg, 0.02mmol) in CH_3CN (5ml) was added and the mixture stirred overnight at room temperature. A dark brown precipitate could be seen to form almost immediately. The dark brown solid was filtrated and dried in *vacuo.*

5.3.2. Preparation of Zn (triflate)$_2$ complex

In a 50ml round-bottom flask donor **8** (21mg, 0.04mmol) was dissolved in hot DCM (5ml). A solution of Zn (triflate)$_2$ (7mg, 0.02mmol) in CH_3CN (5ml) was added and the mixture stirred at room temperature. After 4h no significant changes in solution colour or crystals formation. The solution was heated under reflux for 1.5h, cooled to room temperature, and left covered with aluminium foil with holes allowing a slow evaporation of the solvent. After 20h evaporation of solvent gives small orange crystals.

5.3.3. Preparation of Mn (triflate)$_2$ complex

In a 50ml round-bottom flask donor **8** (21mg, 0.04mmol) was dissolved in hot DCM (5ml). A solution of Mn (triflate)$_2$ (7mg, 0.02mmol) in CH_3CN (5ml) was added and the mixture stirred at room temperature. After 4h no significant changes in solution colour or crystals formation. The solution was heated under reflux for 1.5h, cooled to room temperature, and left covered with aluminium foil with holes allowing a slow evaporation of the solvent. After 20h evaporation of solvent gives small orange crystals.

5.3.4. Preparation of Mn (triflate)$_2$ complex

In a test tube, a solution of DCM (4ml) containing donor **8** (21mg) was added. DCM (2ml) was added slowly creating a layer between the orange solution of donor **8** and the colourless EtOH (2ml) solution of Mn (triflate)$_2$ (7mg) that was added subsequently, taking care of not mixing the solutions. No significant changes when the solutions were mixed by diffusion. After slow evaporation of solvent gives small orange crystals.

5.3.5. Preparation of Cu (triflate)$_2$ complex

In a test tube, a solution of DCM (4ml) containing donor **8** (21mg) was added. DCM (2ml) was added slowly creating a layer between the orange solution of donor **8** and the blue AcCN (2ml) solution of Cu (triflate)$_2$ (12mg) that was added subsequently, taking care of not mixing the solutions. When the solutions were mixed by diffusion a dark precipitate was seen to form. After slow evaporation of solvent gives small black crystals. The procedure was repeated with a large scale.

In a H-cell, a solution of AcCN (4.5ml) containing Cu (triflate)$_2$ (15mg) was added in one of the two containers. Though the other side, a solution of donor **8** (41mg) in DCM (9ml) was added slowly. When the solution containing donor **8** reached the Cu (triflate)$_2$ a dark precipitate was seen to form. After slow evaporation of solvent, black crystals were collected.

6. RESULTS AND DISCUSSION

Below is a discussion of the methods and results obtained for the synthesis of the two target molecules. This includes successful reactions and also reactions which did not give the desired product.

6.1 Discussion of preparation of HMET ester of Isonicotinic Acid, 8

The HMET ester of isonicotinic acid had not been prepared before. Previously, similar compounds were prepared using nicotinic acid (meta) and picolínic acid (ortho)[13]. This difference in the relative position of substituents, allows to obtain a donor with a greater capacity complexing metal due to the relative position.

The synthetic scheme followed for the preparation of the target compound **8** has been successful. The target compound was prepared achieving good yields in most of the reactions.

The esterification reaction between the hydroxymethyl-ET **7** and isonicotic acid using DCC as a coupling agent gives some problems with the purification work-up. The by-product of the utilization of DCC as a coupling agent was the N,N-dicyclohexylurea. The N,N-dicyclohexylurea was not active in the UV lamp. An additional spot in the TLC plate eluting with DCM 2:1 EtOAc appears when the TLC plate was developed using a PMA solution heated with a heating gun. Firstly, the impure donor **8** was stirred with hexane with the aim of dissolving the impurity and so isolate the product by filtration. The impurity remained and an additional chromatographic column eluting with DCM 2:1 EtOAc was required.

A complete description of the characterization of the donor **8** is shown below.

The ^{1}H NMR spectrum of the donor **8** is shown in Figure 24. The chemical shift and the integration of the signals in the aromatic zone between 9-7ppm confirms that the compound has a substituted pyridine ring that is shown in the spectrum as two doublets at 8.60ppm and 7.82ppm. The methylene group attached to the ester group appears as a multiplet at 4.60ppm. The other methylene groups appears as a multiplet at 3.28ppm worth 2H and one singlet worth 4H. The methine group appears at 4.04ppm as a multiplet.

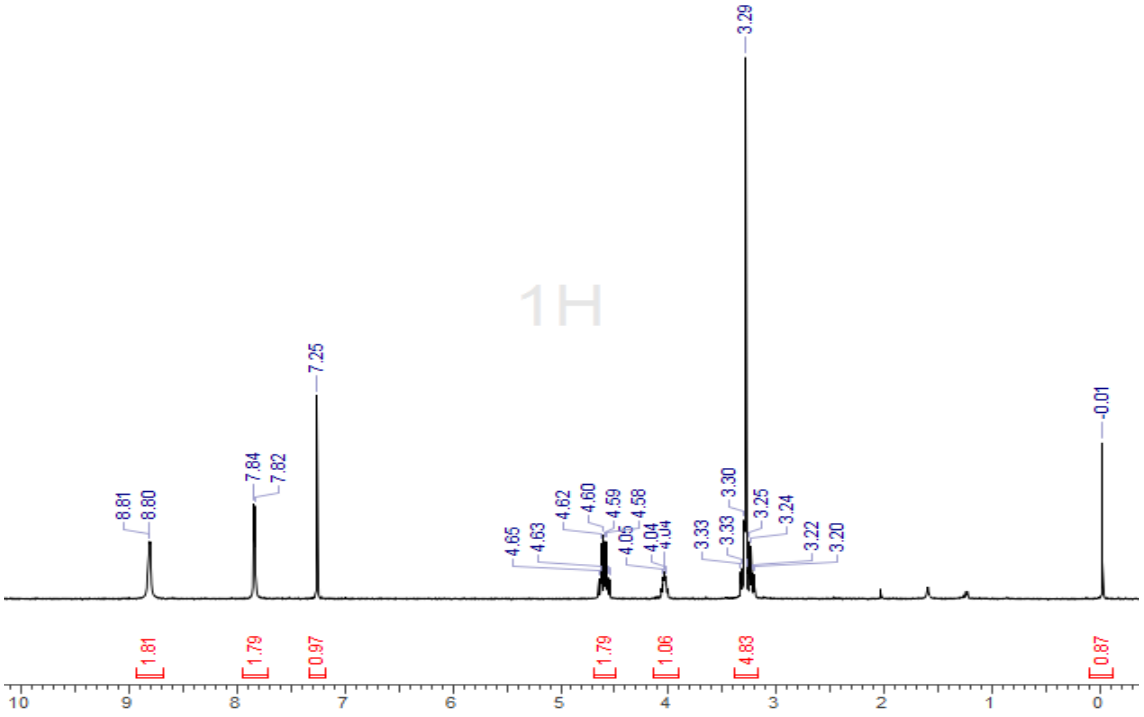


Figure 24. ^{1}H spectrum of the HMET ester of Isonicotinic acid, **8**

The ^{13}C NMR spectrum of the donor **8** is shown in Figure 25.

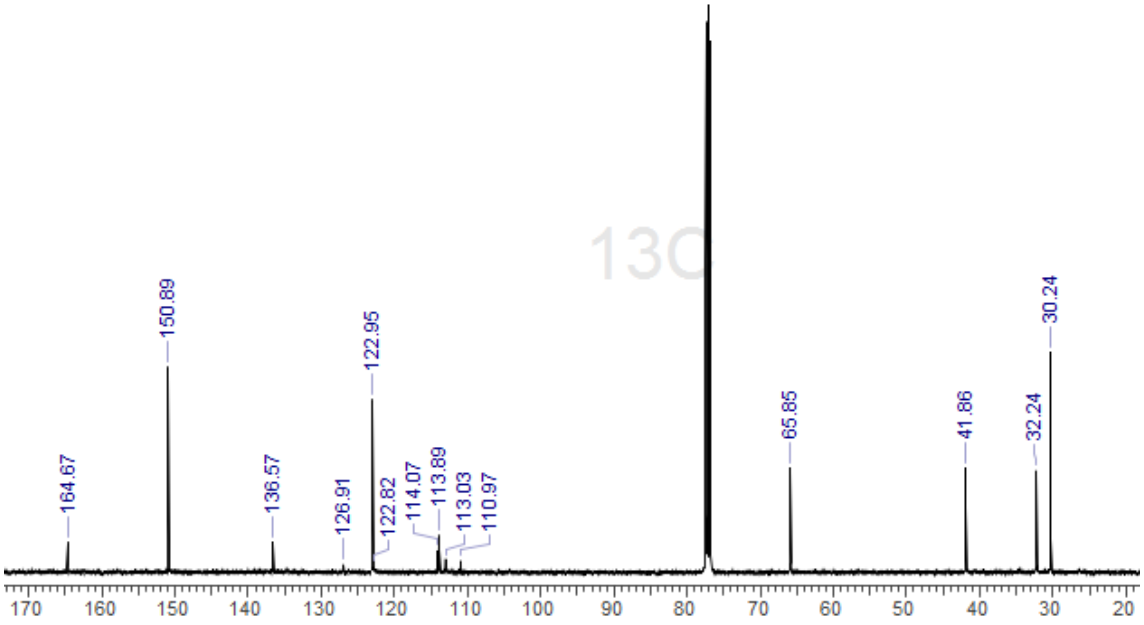


Figure 25. ^{13}C spectrum of the HMET ester of Isonicotinic acid, **8**

Between 70-30ppm appears the signals of sp^3 carbons. At 65.85ppm appears the hydroxymethyl (CH_2O), at 41.86ppm the carbon attached to the hydroxymethyl side chain, and at 32.24, 30.24 the other sp^3 carbons.

Between 170-125ppm appears the sp^2 carbons of the pyridine ring and the carbonyl at 164.67ppm (C=O). At 150.89ppm the carbon attached to the nitrogen (C=N), at

136.57ppm the carbon attached to the carbonyl (C-CO), and at 126.91ppm the carbon ortho to the carbonyl group (CH-C). The peaks between 123-111ppm corresponds to the other sp^2 carbons of the donor.

The IR spectrum of the donor **8** is shown in Figure 26. All the main absorption bands are grouped in the area between 1700-500 cm^{-1}. The more significant and strong absorption band due to the stretching of the carbonyl group appears at 1725 cm^{-1}.

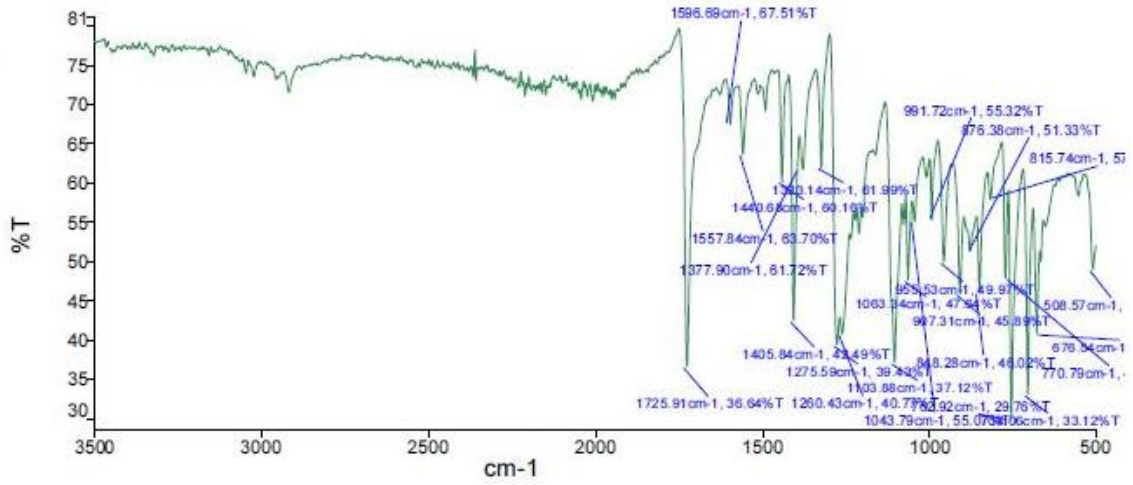


Figure 26. IR spectrum of the HMET ester of Isonicotinic acid, **8**

The chemical analysis of the donor **8** is shown in Table 3. The predicted values agrees with the results obtained.

Table 3. Chemical analysis of HMET ester of isonicotinic acid.

Molecular formula		% Carbon		%Hydrogen		%Nitrogen	
$C_{17}H_{13}NO_2S_8$	Results	39.40	39.47	2.65	2.57	2.85	2.85
	Predicted	39.28		2.52		2.69	

6.2 Discussion of preparation of metal complexes

The first attempt for the preparation of metal complexes with more than one BEDT-TTF donor with a pyridine as a binding group was done with $CuCl_2$.

According with Xu,W. et al[22], a pyridine-substituted BEDT-TTF derivative was synthesized and a charge transfer complex was prepared using $CuCl_2$. In the experimentation carried out in that reference, evidence of the formation of a charge transfer complex between pyridine-substituted BEDT-TTF and the $CuCl_2$ is given by X-ray photo-electron spectroscopy (XPS) and conductivity measurements.

The metal complex prepared with donor **8** and $CuCl_2$ show the same behavior as the donor reported by Xu,W. et al.[22] with only one unit of donor complexed with the metal

center considering the chemical analysis results obtained. The crystals obtained could not be characterised by X-ray crystallography.

Other metals were tried using the trifluoromethanesulfonate salts of zinc (II), manganese (II) and copper (II). The trifluoromethanesulfonate anion is also known as triflate is a good leaving group due to the high stabilization of the charge by resonance.

Only small dark crystals were obtained with the Cu(triflate)$_2$. With the Zn(triflate)$_2$ and Mn(triflate)$_2$ the orange crystals obtained correspond to the precipitation of the donor **8**. The melting point of the donor **8** was 181.5-182ºC and by comparing with the m.p. of the other orange crystals, it was established that thet do not correspond to metal complexes but only to the donor **8**, as shown in Table 4.

Table 4. Comparation of melting points of the metal complexes

Compound	Melting point (ºC)
Donor **8**	181-182
Donor **8** + Zn(triflate)$_2$	180-181
Donor **8** + Mn(triflate)$_2$	182-183
Donor **8** + Cu(triflate)$_2$	161-163

The results of the chemical analysis of the different metal complexes prepared is shown in Table 5. The prediction of the molecular formula was acquired using the web application JASPER.[23]

Table 5. Chemical analysis of the metal complexes

Molecular formula		**% Carbon**		**%Hydrogen**		**%Nitrogen**	
$C_{17}H_{13}NO_2S_8CuCl_2$	Results	29.39	29.45	1.76	1.82	2.52	2.57
	Predicted	31.21		2.00		2.14	
$C_{18}H_{13}NO_5S_9CuF_3$	Results	29.05	29.12	2.13	2.02	2.21	2.21
	Predicted	29.52		1.79		1.81	

The compounds prepared using copper as the metallic center allows the formation of metal complexes. The objective was to prepare metal complexes with more than one BEDT-TTF based ligands but in both cases the chemical analysis confirms that only one unit of donor was complexed with the metallic center. The complex prepared with the donor **8** and Cu(triflate)$_2$ according to the chemical analysis may have suffered a reduction process. In the laboratory there is not available any instrument for magnetic measurements, but would have allowed confirm this fact.

Further studies will be performed in this area, only an approximation has been done in this work.

The donor prepared was transferred to PhD student Jordan Lopez at Nottingham Trent University that is dedicated to the electrocrystallization of BEDT-TTF derived compounds.

So far, electrocrystallization experiments with tetrabutylammonium salts of ClO_4^-, PF_6^-, BF_4^-, Cl^-, I^-, and Br^- using DCM as solvent gave only black powders. This indicates that the donor had been oxidized but the products could not be characterised by X-ray crystallography.

In addition, hot diffusions of donor **8** with tetracyanoquinodimethane (TCNQ), TCNP-F2, TCNQ-F4, and TCNQ-2,5-bis(2-hydroxyethoxy) gave black powders. Again this indicates formation of charge transfer compounds, but they could not be characterised.

6.3 Discussion of preparation of HMET triester of trimesic acid, 16

Two approaches were proposed for the synthesis of target compound **16**.

The first approach requires first the synthesis of the hydroxymethyl thione triester of trimesic acid **12**. The coupling reaction between triester **12** and the unsubstituted thione **5** using $P(OMe)_3$ should produce the desired product **16**.

The hydroxymethyl thione **9** was prepared by pericyclic reaction Diels Alder type ([4+2] cycloaddition) of trithione **2** and allyl alcohol with a 54% yield.

The hydroxymethyl thione triester of trimesic acid **12** was prepared using two different reactions. The first attempt includes the use of a carbodiimide activator, EDC. The main advantage of the use of EDC instead of DCC was that it allows an easier purification due to the presence of an amino group in the side product generated in the coupling reaction. A basic compound, could be easily removed by treatment with aqueous HCl, and then the product **12** isolated by chromatographic column. The reaction was succesful and hydroxymethyl thione triester of trimesic acid **12** was prepared with a 98% yield. A few hours later, white needles grew on the walls of the flask containing the dry product **12**, which was dark orange colour. There is no clear explanation about the formation of these white needles. Possibly, the urea by-product of the use of EDC remains in a small amount in the purified solid.

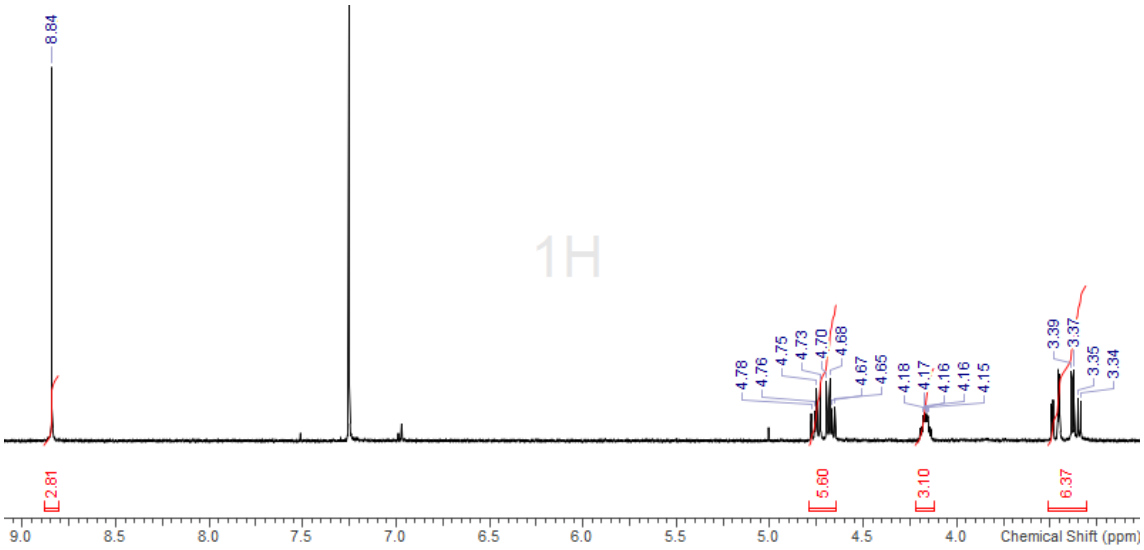


Figure 27. ^{1}H NMR spectrum of hydroxymethyl thione triester of trimesic acid, **12**

The molecular peak in the mass spectrum of the compound prepared **12** is shown in Figure 28. Firstly, the spectrum was acquired using electrospray ionization (ESI) as the ionization method, but no molecular peaks could be seen. Then, another spectrum was acquired using matrix-assisted laser desorption/ionization (MALDI) and the observed data corresponds to the theoretical isotope profile [M]+·. The molecule contain 15 sulfur atoms and [M+2]+· peak should contain information about the ^{34}S isotope (4.2% abundance).

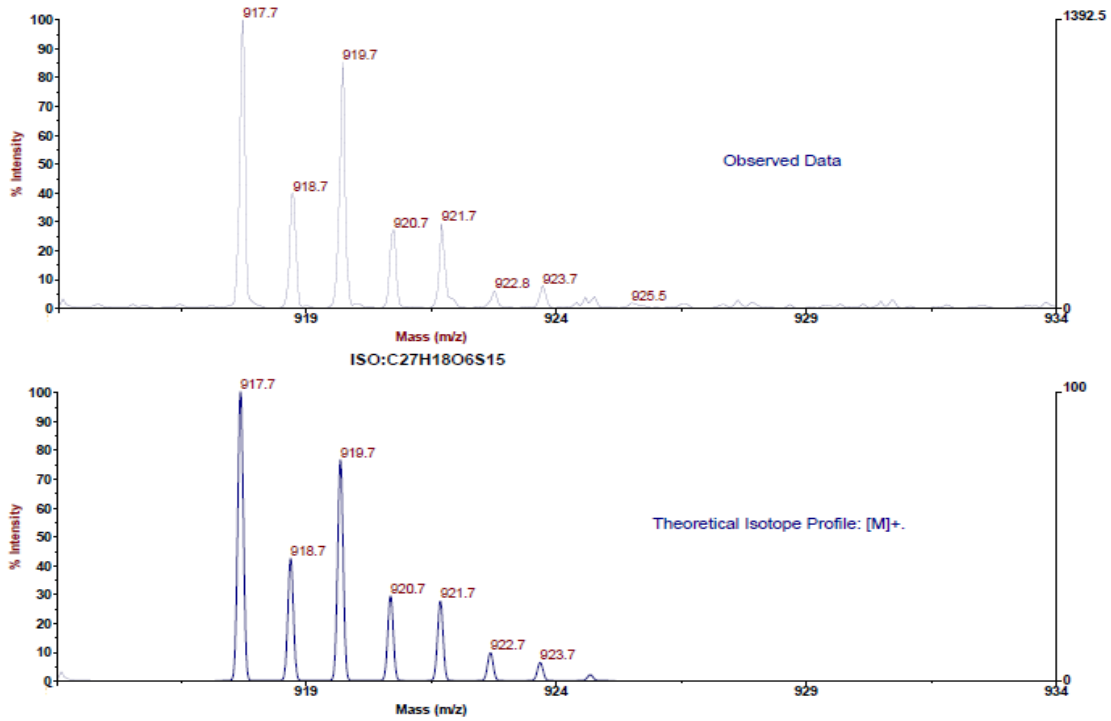


Figure 28. Detail of the mass spectrum of hydroxymethyl thione triester of trimesic acid, **12**

The hydroxymethyl thione triester of trimesic acid **12** had a low solubility in $CHCl_3$ and for preparing the triester compound with the three BEDT-TTF units was necessary to prepare first the hydroxymethyl oxo compound triester of trimesic acid **17** and then do the coupling reaction with the unsubstituted thione. The solubility of compound **12** was low in $CHCl_3$ and for avoiding a partial oxidation, the compound was not oxidized to the oxo compound **17**.

Instead, coupling reaction was carried out using dimethyl thione **13** as shown in Figure 21 and also using the corresponding oxo compound **14**. The aim of this change is to add a moiety that increases the solubility of the resulting compound in organic solvents. According to Devonport, W et al.[19] methylthio substituents are known to enhance the solubility of THF derivatives without significantly affecting the redox properties.

The reaction between dimethyl thione **13** and hydroxymethyl thione triester of trimesic acid **12** gives a solid ball that was partially dissolved in $CHCl_3$ and the TLC plate eluting with DCM 10:1 EtOAc confirms that there was only starting material. Probably, the hydroxymethyl thione triester of trimesic acid **12** reacts with itself producing polymeric materials that are non-soluble, in spite of that this possibility was not confirmed by spectroscopic methods.

The reaction between oxo compound **14** and hydroxymethyl thione triester of trimesic acid **12** gives a solid and a coloured reaction. The solvent was evaporated, and after running a chromatographic column four different fractions were collected. The changes made on the previous reaction, were the addition of more equivalents of oxo compound **14** and a more diluted solution using double volume of $P(OMe)_3$. The aim of this changes were to enhance the possibility of the reaction between the oxo compound and the trithione **12.** The first fraction according to the ^1H NMR corresponds to the homocoupling of the oxo compound **14**. From the other three fractions no clear information was found.

After different attempts, it was not possible to identify the desirable reaction product from the coupling reactions.

The second approach proposed for the synthesis of the target compound **16** includes the preparation of the HMET with the subsequent esterification reaction with a carbodiimide activator, EDC. The reaction was carried out in a small scale.

The first problem of the reaction was the low solubility of the product **16** in DCM. A large amount of solvent (120ml) was added with the aim of dissolving as much as possible the product. Nevertheless, during the extractions with HCl for removing the remaining EDC and the urea by-product some product precipitated at the interface.

Furtheremore, as some of the product remains in the solution as a suspension, some of the product was also lost during the drying step. Even so, 10 mg of the orange product were collected after the chromatographic column eluting with DCM 10:1 EtOAc.

The characterization was done by ^{1}H NMR spectroscopy.

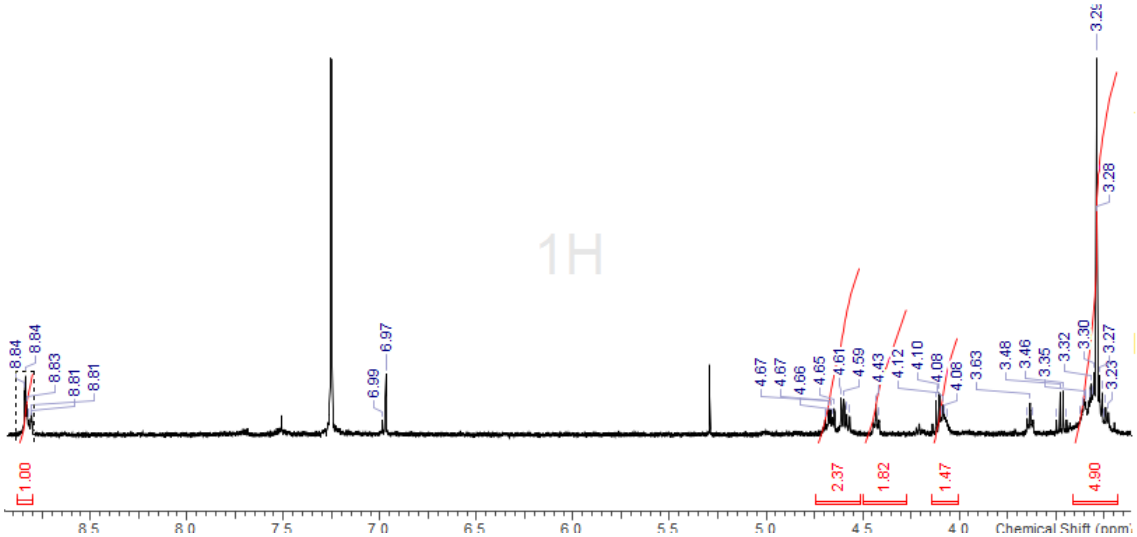


Figure 29. ^{1}H spectrum of HMET triester of trimesic acid

In the spectrum, appears some signals due the presence of impurities but all the expected signals for the product **16** could be seen in the ^{1}H spectrum. At 8.84ppm the peak due the presence of the aromatic protons appers like a singlet as expected, although small signals at 8.81ppm. A ^{13}C NMR was not acquired due the low solubility of the compound in $CDCl_3$ and other deuterated solvents like DMSO-d_6.

Things that have not been able to study is the possibility of, after the esterification reaction, simply filtering the reaction mixture and washing the orange solid with small amounts of cold $CHCl_3$. Luckily, the orange solid may be free of most of the impurities which were shown in the work carried out. Also, the possibility of carrying out the reaction with 1,3,5-benzenetricarbonyl chloride in pyridine with the HMET. A starting point for future studies in the preparation of BEDT-TTF donors with three fold symmetry have been established.

7. CONCLUSIONS

The preparation of a BEDT-TTF or ET derivatives with a hydroxymethyl group (HMET) was carried out successfully and HMET ester of isonicotinic acid was prepared. Only metal complexes with copper ions were prepared and none of them presents more than one ET unit.

Two approaches were proposed for the synthesis of the HMET triester of trimesic acid considering the two key reactions for the preparation of BEDT-TTF derivatives: the coupling reactions and the esterification. The experimentation carried out shows better results when the coupling reaction to prepare HMET takes place first, with the subsequent esterification reaction. In any case, this study has not done a thorough analysis of the problems and there are still some issues that could not be answered with experimentation carried out, but at least, has established a starting point for future studies.

Further developments in this field will allow to prepare more compounds with different cores and different functionalities as thioethers or amides.

8. REFERENCES

(1) Nottingham Trent University https://www.ntu.ac.uk/apps/staff_profiles/staff_directory/125668-2/26/john_wallis.aspx (accessed May 12, 2016).

(2) Wallis, J. D.; Griffiths, J.-P. Substituted BEDT-TTF Derivatives: Synthesis, Chirality, Properties and Potential Applications. *J. Mater. Chem.* **2005**, *15* (3), 347.

(3) Wang, Q.; Martin, L.; Blake, A. J.; Day, P.; Akutso, H.; Wallis, J. D. Coordination Chemistry of 2,2'-Bipyridyl- and 2,2':6',2"-Terpyridyl-Substituted BEDT-TTFs: Formation of a Supramolecular Capsule Motif by the Iron(II) Tris Complex of 2,2'-Bipyridine-4-Thiomethyl-BEDT-TTF. *No Publ.* **2016**.

(4) Griffiths, J. P.; Brown, R. J.; Day, P.; Matthews, C. J.; Vital, B.; Wallis, J. D. Synthesis of Bis(ethylenedithio)tetrathiafulvalene Derivatives with Metal Ion Ligating Centres. *Tetrahedron Lett.* **2003**, *44* (15), 3127–3131.

(5) Brown, R. J.; Camarasa, G.; Griffiths, J. P.; Day, P.; Wallis, J. D. Synthesis of BEDT-TTF Derivatives with Carboxylic Ester and Amide Functionalities. *Tetrahedron Lett.* **2004**, *45* (26), 5103–5107.

(6) Griffiths, J. P.; Arola, A. A.; Appleby, G.; Wallis, J. D. Synthesis and Reactivity of Amino-Substituted BEDT-TTF Donors as Building Blocks for Bifunctional Materials. *Tetrahedron Lett.* **2004**, *45* (13), 2813–2816.

(7) Avarvari, N.; Wallis, J. D. Strategies towards Chiral Molecular Conductors. *J. Mater. Chem.* **2009**, *19* (24), 4061–4076.

(8) Brown, R. J.; Brooks, A. C.; Griffiths, J.-P.; Vital, B.; Day, P.; Wallis, J. D. Synthesis of Bis(ethylenedithio)tetrathiafulvalene (BEDT-TTF) Derivatives Functionalised with Two, Four or Eight Hydroxyl Groups. *Org. Biomol. Chem.* **2007**, *5* (19), 3172–3182.

(9) Montgomery, L. K. Chemical Synthesis and Crystal Growth Techniques. In *Organic Conductors: Fundamentals and Applications*; Farge, J. P., Ed.; Marcel Dekker Inc.: New York, 1994; pp 115–146.

(10) Hansen, T. K.; Becher, J.; Jørgensen, T.; Varma, K. S.; Khedekar, R.; Cava, M. P. 4,5-Dibenzoyl-1,3-Dithiole-1-Thione. *Org. Synth.* **1996**, *73*, 270–274.

(11) Neiland, 0. Ya; Katsens, Y. Y.; Kreitsberga, Y. N. N. *Zh. Org. Khim* **1989**, *25*, 658.

(12) Leurquin, F.; Ozturk, T.; Pilkington, M.; Wallis, J. D. New Precursors for Preparing Organic Conducting Materials : Synthesis of (R) -Hydroxymethylbis (Ethylenedithio) Tetrathiafulvalene , and the Ring Expansion of a Cyclic Sulfate Ester. *J. Chem. Soc., Perkin Trans.* **1997**, No. 21, 3173–3177.

(13) Wang, Q.; Day, P.; Griffiths, J.; Wallis, J. D. Synthetic Strategies for Preparing BEDT-TTF Derivatives Functionalised with Metal Ion Binding Groups. *New J. Chem.* **2006**, *30*, 1790–1800.

(14) Bates, R. B.; Schaefer, J. P. *Research Techniques in Organic Chemistry*, 1st ed.; Prentice-Hall Inc: Englewood Cliffs, 1971.

(15) Science for live: Reflux http://www.organicchem.org/oc2web/lab/exp/lp/lpreflux.html (accessed May 20, 2016).

(16) Fessenden, R. J.; Fessenden, J. S.; Feist, P. *Organic Laboratory Techniques*, 3rd ed.; Brooks/Cole cengage learning: Belmont, 2001.

(17) Mohrig, J. R.; Noring, C.; Schatz, P. F. *Techniques in Organic Chemistry*, 3rd ed.; W.H. Freeman: New York, 2010.

(18) University College London School of Pharmacy. CHN Elemental Microanalysis https://www.ucl.ac.uk/pharmacy/facilities/research-services/chn-elemental-microanalysis (accessed May 10, 2016).

(19) Devonport, W.; Bryce, M. R.; Marshallsay, G. J.; Moore, A. J.; Goldenberg, L. M. Aryl Ester Dendrimers Incorporating Tetrathiafulvalene Units: Convergent Synthesis, Electrochemistry and Charge-Transfer Properties. *J. Mater. Chem.* **1998**, *8* (6), 1361–1372.

(20) Suzuki, T.; Yamamoto, T.; Tezuka, Y. Constructing a Macromolecular K3,3 Graph through Electrostatic Self-Assembly and Covalent Fixation with a Dendritic Polymer Precursor. *J. Am. Chem. Soc.* **2014**, *136* (28), 10148–10155.

(21) Miller, T. M.; Kwock, E. W.; Neenan, T. X. Synthesis of Four Generations of Monodisperse Aryl Ester Dendrimers Based on 1,3,5-Benzenetricarboxylic Acid. *Macromolecules* **1992**, *25*, 3143–3148.

(22) Xu, W.; Zhang, D. Q.; Li, H. X.; Zhu, D. B. New Electron Donors: BEDT-TTF Derivatives Bearing a Pyridine Group; Synthesis, Crystal Structure, Electrochemical Studies and the Formation of Charge Transfer Complexes. *J. Mater. Chem.* **1999**, *9* (6), 1245–1249.

(23) Potvin, P. G. JASPER 2.0 JavaScript Percentage Elemental Results Calculator http://www.chem.yorku.ca/profs/potvin/Jasper/jasper2.htm (accessed Apr 10, 2016).

9. ANNEX

All the solvents in Table 1 are in this annex with his hazards and handling.

Acetone 99.5% Fisher

Hazards: Highly flammable. Irritating to eyes. Repeated exposure may cause skin dryness or cracking. Vapours may cause drowsiness and dizziness.

Handling: Product should be used in accordance with good industrial principles for handling and storing of hazardous chemicals. Avoid vapour inhalation, skin and eye contact. Do not use contact lenses. Avoid vapour formation and ignition sources.

Acetonitrile (CH_3CN), 99.5% Fisher

Hazards: Highly flammable liquid and vapour. Harmful if swallowed, in contact with skin or if inhaled. Causes serious eye irritation.

Handling: Keep away from ignition sources. Avoid contact with skin an eyes. Avoid inhalation of vapour or mist.

Chloroform ($CHCl_3$), 99.8% Fisher

Hazards: Irritant in case of skin contact, of eye contact, of ingestion, of inhalation. Permeator in case of skin contact with slightly hazardous effects.

Handling: Do not breathe gas, fumes, vapour or spray. Wear suitable protective clothing. In case of insufficient ventilation, wear suitable respiratory equipment.

Cyclohexane, 99% Fisher

Hazards: Slightly hazardous in case of skin contact irritant and permeator effect, of eye contact irritant effect, of ingestion, of inhalation. May cause drowsiness or dizziness. May be fatal if swallowed and enters airways.

Handling: Keep away from heat. Keep away from sources of ignition. Wear suitable protective clothing. In case of insufficient ventilation, wear suitable respiratory equipment.

Dichloromethane (DCM), 99% Fisher

Hazards: Irritant in case of skin contact and eye contact. May cause drowsiness or dizziness Suspected of causing cancer. May cause damage to organs throught prolongated or repeated exposure.

Handling: Avoid breathing vapours. Wear suitable protective clothing. In case of insufficient ventilation, wear suitable respiratory equipment.

Diethyl Ether (Et_2O), 99% Fisher

Hazards: Irritant in case of skin contact, of eye contact, of ingestion, of inhalation. Slightly permeator in case of skin contact with hazardous effects.

Handling: Keep away from heat. Keep away from sources of ignition. Wear suitable protective clothing. In case of insufficient ventilation, wear suitable respiratory equipment.

Dimethylformamide (DMF), 99% Fisher

Hazards: The acute toxicity of DMF is low by inhalation, ingestion, and skin contact. Contact with liquid DMF may cause eye and skin irritation. DMF is an excellent solvent for many toxic materials that are not ordinarily absorbed and can increase the hazard of these substances by skin contact.

Handling: Wash thoroughly after handling. Use spark-proof tools and explosion proof equipment. Avoid contact with eyes, skin, and clothing.

Dimethyl sulfoxide (DMSO), 99.9% Fisher

Hazards: Slightly irritant effect in case of inhalation (lung irritant). Slightly irritant and permeator in case of skin contact,irritant if there are eye contact or ingestion.

Handling: Keep away from heat. Keep away from sources of ignition. Wear suitable protective clothing. In case of insufficient ventilation, wear suitable respiratory equipment.

Ethanol (EtOH), 99.5% Fisher

Hazards: Highly flammable. Irritation of eyes. Swallowing causes narcotic effects. Repeated excessive intake causes liver damage

Handling: Keep away from heat. Keep away from sources of ignition. Wear suitable protective clothing.

Ethyl acetate (EtOAc), 99.9% Fisher

Hazards: Hazardous in case of ingestion, of inhalation. Slightly hazardous in case of skin contact irritant and permeator effect, of eye contact irritant effect.

Handling: Keep away from heat. Keep away from sources of ignition. Wear suitable protective clothing. In case of insufficient ventilation, wear suitable respiratory equipment.

Hexane, 95% Fisher

Hazards: Hazardous in case of skin contact permeator effect, of ingestion, of inhalation. Slightly irritant in case of skin contact, of eye contact.

Handling: Keep away from heat. Keep away from sources of ignition. Wear suitable protective clothing. In case of insufficient ventilation, wear suitable respiratory equipment.

Methanol (MeOH), 99.8% Fisher

Hazards: Highly flammable liquid. May cause skin irritation and central nervous system depression. May be absorbed through the skin. May cause kidney damage and respiratory and digestive tract irritation.

Handling: Protect self against physical damage. Avoid contact with skin, eyes and clothing. Do not breathe vapor. Use only in well ventilated areas.

Toluene, 99.5% Fisher

Hazards: Highly flammable liquid and vapour. May be fatal if swallowed and enters airways and cause damage to organs through prolongated or repeated exposure. May cause drowsiness or dizziness.

Handling: Keep away from heat. Keep away from sources of ignition. Wear suitable protective clothing. In case of insufficient ventilation, wear suitable respiratory equipment.

Tetrahydrofuran (THF), 99.5% Fisher

Hazards: Irritant in case of skin contact or eye contact. Slightly hazardous in case of skin contact with permeator effect. Highly flammable liquid and vapour

Handling: Keep away from heat. Keep away from sources of ignition. Wear suitable protective clothing. In case of insufficient ventilation, wear suitable respiratory equipment.