

SYNTHESIS OF DIPYRENE-PHENOTHIAZINE DERIVATIVES



A SPECIAL PROJECT SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENT FOR
THE DEGREE OF BACHELOR OF SCIENCE (INDUSTRIAL CHEMISTRY)
DEPARTMENT OF CHEMISTRY, FACULTY OF SCIENCE

เอกสารนี้เป็นเอกสารที่จัดทำขึ้นเพื่อใช้ในการเรียนการสอนเท่านั้น ไม่สามารถนำออกจำหน่าย การค้า
ไม่ว่ากรณีใดๆ ทั้งสิ้น อีกทั้งห้ามมิให้คัดลอกเอกสารฉบับนี้ไปเผยแพร่ในที่สาธารณะโดยไม่ได้รับอนุญาต
ของเอกสารทุกครั้งที่มีการนำไปใช้

KING MONGKUT'S INSTITUTE OF TECHNOLOGY LADKRABANG
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Title	Synthesis of dipyrene-phenothiazine derivatives
Students	Mr. Natanan Rengsomboonsuk Student ID 59050402 Miss Poschanun Sasom Student ID 59050449
Degree	Bachelor of Science (Industrial Chemistry)
Department	Chemistry
Faculty	Science
University	King Mongkut's Institute of Technology Ladkrabang (KMITL)
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Advisor	Asst. Prof. Dr. Karoon Sadorn

Abstract

This special project focused on the design and synthesis of dipyrene-phenothiazine derivatives, namely 10-benzyl-3,7-di(pyren-1-yl)-10*H*-phenothiazine (BDPy-PTZ) and 10-octyl-3,7-di(pyren-1-yl)-10*H*-phenothiazine (ODPy-PTZ). From the retrosynthesis, both compounds could be synthesized from a commercially available phenothiazine by using the same synthetic route, including alkylation, bromination, and Suzuki-Miyaura cross-coupling reactions with the pyrene boronic acid. Recently, BDPy-PTZ was successfully prepared as a yellow solid in 20 %overall yield (for 3 steps). On the other hand, for ODPy-PTZ, only 3,7-dibromo-10-octyl-10*H*-phenothiazine, a precursor for Suzuki-Miyaura cross-coupling reaction, was synthesized as a pale yellow oil in 46 %overall yield (for 2 steps). In the future, this precursor will be subjected to react with the pyrene boronic acid to provide the desired ODPy-PTZ.

Keywords: Organic light-emitting diodes, Suzuki-Miyaura cross-coupling reaction, Dipyrene-phenothiazine

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Natanan Rengsomboonsuk

Poschanun

Sasom

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Abbreviation

Abbreviation	Explanation
OLEDs	Organic light-emitting diodes
ODPy-PTZ	10-Octyl-3,7-di(pyren-1-yl)-10 <i>H</i> -phenothiazine
BDPy-PTZ	10-Benzyl-3,7-di(pyren-1-yl)-10 <i>H</i> -phenothiazine
LUMO	Lowest unoccupied molecular orbital
HOMO	Highest occupied molecular orbital
PTZ	Phenothiazine
TLC	Thin-layer chromatography
sat. NaCl	Saturated sodium chloride
CDCl ₃	Deuterated chloroform
NBS	<i>N</i> -bromosuccinimide
ETM	Electrons transport material
HTM	Holes transport material

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CHAPTER 1

Introduction

1.1 Research Motivation

Organic light-emitting diodes (OLEDs) are light-emitting devices, which are made from π -conjugated organic compounds as electroluminescent materials in diode devices. OLEDs are outstanding materials of solid-state light sources for diverse utilizations such as small and large displays, automotive lighting, solid-state lighting, and signage. For commercial appliances, OLEDs have to operate their best since they were determined with their capability and stability of the device [1]. Therefore, the design of organic luminescent compounds, generating effectively light is one of the largest remaining challenges in the continued development of OLEDs and other devices used in the displays.

Interestingly, OLEDs have received considerable attention from academic researchers and industries since the exploration of organic light-emitting diodes. The light-emitting organic compounds have been designed and improved. Subsequently, they are still researched to find organic materials are simple to synthesize, developed process, and high efficiency. The OLED technologies have been employed prosperously for a flat panel display and solid-state lighting applications. Mostly, they are synthesized by utilizing conjugated building blocks. For instance, anthracene, pyrene, phenothiazine, and carbazole have been prosperously employed for creating and synthesizing light-emitting active layers for OLED devices. Nevertheless, the existent OLEDs still have some drawbacks to gain purely strong emission with lower power utilization which is decided by driving the voltage and efficiency of the devices [2].

Consequently, this special project focused on the design and synthesis of phenothiazine derivatives substituted with pyrene, named 10-benzyl-3,7-di(pyren-1-yl)-10*H*-phenothiazine (BDPy-PTZ) and 10-octyl-3,7-di(pyren-1-yl)-10*H*-phenothiazine (ODPy-PTZ).

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1.2 Objective of the study

To design and synthesize phenothiazine derivatives substituted with pyrene, named 10-benzyl-3,7-di(pyren-1-yl)-10*H*-phenothiazine (BDPy-PTZ) and 10-octyl-3,7-di(pyren-1-yl)-10*H*-phenothiazine (ODPy-PTZ).

1.3 Scopes of the study

1.3.1 To prepare 10-benzyl-10*H*-phenothiazine and 10-octyl-10*H*-phenothiazine by using an alkylation reaction of phenothiazine with *n*-octyl bromide and benzyl bromide, respectively.

1.3.2 To prepare 10-benzyl-10*H*-phenothiazine and 10-octyl-10*H*-phenothiazine substituted with bromine based on a bromination reaction with NBS.

1.3.3 To prepare dipyrene-phenothiazine derivatives, BDPy-PTZ and ODPy-PTZ, by using a Suzuki-Miyaura cross-coupling reaction between dibromophenothiazine derivatives and pyrene boronic acid.

1.4 Benefits of the study

1.4.1 A pyrene unit of this phenothiazine derivatives could improve their optical properties, especially their fluorescence properties.

1.4.2 Phenothiazine derivatives substituted with pyrene, BDPy-PTZ and ODPy-PTZ, obtained from this project might be used as new organic emissive materials for OLEDs.

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CHAPTER 2

Theory and Literature Reviews

2.1 Organic light-emitting diodes (OLEDs)

Organic light-emitting diodes are a new technology, which can take the place of the existing lighting technologies for solid-state light sources. They are a solid-state device comprised of very thin films of organic compounds in the electroluminescent layer. Besides, an emissive electroluminescent layer is designed to be in between two thin-film conductive electrodes. This layer is usually made of carbon-based compounds, which emit light of particular wavelength (colour) such as red, green, or blue light when have taken an electric current. Consequently, the photon energy and the colour of the emitted light are essentially decided by the band gap energy of the material.

Organic light-emitting diodes have been created good process as their first presentation based on small molecule organic materials by C. W. Tang and S. A. Van Slyke who worked at Eastman Kodak in 1987. They created the bilayer heterojunction small molecular organic light-emitting diodes (SMOLEDs) [3] consisted of two organic semiconducting layers sandwiched between contact electrodes. One of the active layers was as hole transport, while the other one made of tris(8-hydroxyquinoline)aluminum (Alq_3) provided electrode transport and light generation. Its simplest, OLEDs with just one layer, capable of transporting both holes and electrons and emitting light could be built. However, more layers were typically needed to enhance device operation.

In 1992, Gustafsson et al. presented the first pliable OLED on a polyethylene terephthalate (PET) substrate. Polyaniline (PANI) was employed as the transparent hole-injection contact yielding comparable efficiency to inflexible ITO-based device [4]. Subsequently, in 1994, Kido et al. produced the first white OLEDs using a double emitting layer structure which is derived by mixing blue and orange emission in the same device [5]. The device displayed white emission covering a wide range of the visible region with a maximum luminance of 3400 Cd/m^2 [6]. Though, this device

included red, green, and blue light-emitting materials to generate white light. The OLEDs device was also compatibility between substrates and microfluidic structures.

Besides, it was extremely thin to estimate 400 nm [6]. Their resolution processability made them simple to manufacture and potentially low cost. The discriminating colour and functionality of the devices could be created and simply tuned the properties of the organic materials by converting the functional groups or ligands. Significantly, OLEDs could be produced as flexible and transparent. This created many probabilities for creative and apparent application, for example, smartphones. However, OLEDs still had some problems related to their stability. Hence, extensive effort has been made the process, device structures and synthetic materials to expand the lifetime of the devices [7]. Additionally, OLEDs are still developed for improving device performance.

2.1.1 Electroluminescence [8]

Electroluminescence is an optical phenomenon and electrical phenomenon where organic compounds emit light as an electric current or a strong electric field is passed through it. The phenomenon of electroluminescence can be considered as both electrical and optical. It occurs because of radiative recombination of holes and electrons of the material. The recombination of these pairs can induce the emission of light. In an OLED device, the electric currents pass through into the device. The cathode also injects electrons into the emissive layer, during holes are injected from the anode. And then these charges combine in the emissive layer, the light-emitting layer is excited as a result of the recombination energy of electrons and holes. They emit light when returning to the ground state. Besides, the colour of the emitted light occurs depending on the different energy between the highest occupied molecular orbital (HOMO) and the lowest unoccupied molecular orbital (LUMO) of the organic molecules, which the material employed since the emissive layer is consisted of. Furthermore, the amount of electric current is applied to influence the intensity of the light-emitting, and the colour of light is decided by the type of electroluminescent material chosen.

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2.1.2 Basic OLED Structure [9]

The basic OLED cell structure comprises of a stack of thin organic layers sandwiched between an anode and a cathode (Figure 2.1). Breakdown of an OLED structure:

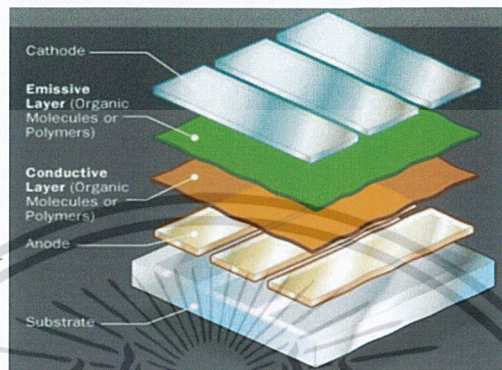


Figure 2.1 Structure of OLEDs [9]

1. Substrate: It is made of plastic, foil or even glass. Its function is as the base of the OLED structure.

2. Anode: The anode component should be transparent. The anode is as injecting holes into the different layers. It also has a great work function which is also known as the emitter.

3. Organic layers: They contained conductive polymer made of organic molecules such as hydrogen and carbon. They are placed above the anode layer.

3.1 Conducting layer: It is also comprised of organic plastic molecules. It helps to carry holes from the anode.

3.2 Emissive Layer: This layer is composed of organic materials as well, but it is different from the conductive layer. The emissive layer where the electrical energy is directly transformed into light. It aids to carry electrons from the cathode and emits light. The colour of the light depends on the type of organic molecule utilized for the progress. Additionally, the light is also emitted depending on the intensity. When the current is applied more, the light will be more brilliant as a result of recombination of electron-hole pairs and form excitons.

4. Cathode: It is the top part of the OLED. The cathode injects electrons when an electrical current passes through the OLED. The cathode is also known as the conductor.

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2.1.3 The layer of OLED [10]

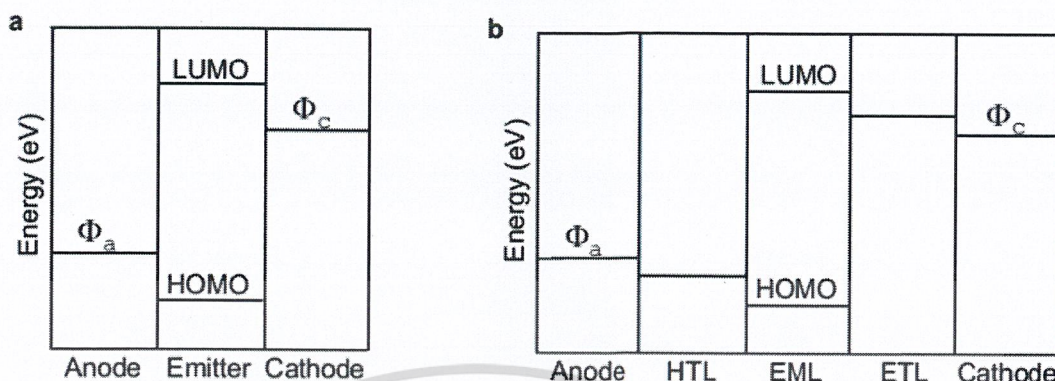


Figure 2.2 The single-layer (a) and the multilayer (b) of OLED [10]

For single-layer device illustrated in Figure 2.2a, the materials must have the characteristics of acquiring both holes and electrons from the electrodes and moving them as well as emissive features. Due to the obstacle of giving a material, which has the multiple functions and various materials have each function of charge acceptance from the electrodes, charge transport, charge blocking and emission are utilized together in devices. Thus, the single-layer device needs to develop the properties and designs to the multi-layer device. For the multi-layer (Figure 2.2b) devices have been designed to enhance charge injection and mobility. The multi-layer device, which is consisted of a stack of organic layers to develop the injection, transport and recombination of charges within the emissive layer (EML). Besides, the efficiency of an OLED is decided by charge balance, the radiative collapse of excitons, and light extraction. And the hole current is also restricted by injection and the electron current. Therefore, the multi-layer device has hole-transporting materials (HTMs) for accepting hole carriers from the anode through the hole-injection layer and has electron-transporting materials (ETMs) for accepting electron carriers injected from the cathode through the electron-injection layer to develop and control charge injection and transport in OLEDs.

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2.1.4 OLEDs device structure and operation [11]

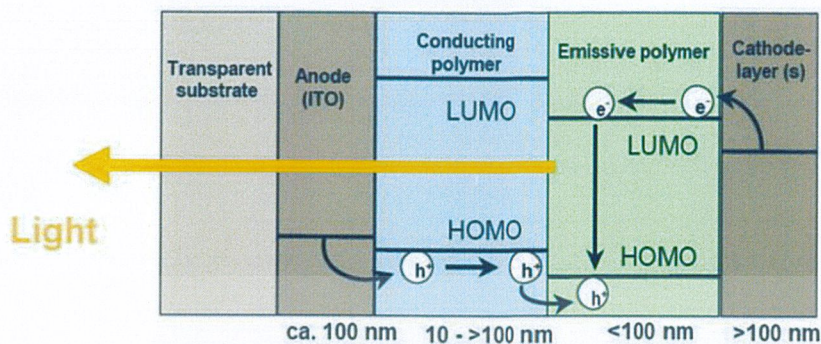


Figure 2.3 Operation principle of OLEDs [12]

In the process of OLEDs (Figure 2.3), when voltages are applied to OLED, the electrical currents flow from the cathode to the anode through the organic layers. Electrons are simulated and moved from the cathode to the LUMO level the emissive layer, also electrons from conductive layer (anode) are displacing to move into the HOMO level of the emissive layer. Then, electrons and holes meet and recombine in the emissive layer and forming excitons. While they were recombining in the emissive layer, they were at the excited state and then gradually returned to their ground state thus the light is emitted. Furthermore, the recombination of the holes and electrons induces the invention of a photon with a frequency to give the energy gap ($E=h\nu$) between the LUMO and HOMO levels of the emitting molecules. Then, the colour of the light created can be changed following the type of organic molecule employed for its progress. Another determinant of the light generated is its intensity, which depends on the electrical power is applied to devices [13].

2.1.5 The advantages of OLEDs [14]

1. OLEDs are flexible and they are very simple to produce OLED displays or other OLED devices such as mobile phones, cameras, wearable devices.
2. Their size is small and they are also lightweight and very thin.
3. OLEDs consume low energy and are appropriate for devices demanding low energy consumption such as smartphones, gaming consoles, media players.
4. OLEDs have a wide field of view. As OLEDs provide light on their own, also they have an expansive viewing range.

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5. They are high brightness and contrast.

2.1.6 The disadvantages of OLEDs [14]

1. Their lifetime is shorter than the other display technologies because of blue organic material.
2. A manufacturing process is expensive.
3. They are sensitive to water and oxygen. Thus, OLED can be simply damaged.
4. OLED displays are even worse when subjected to direct sunlight.
5. The ability of the light-emitting is gradually reduced.

2.2 Fluorophore [15,16]

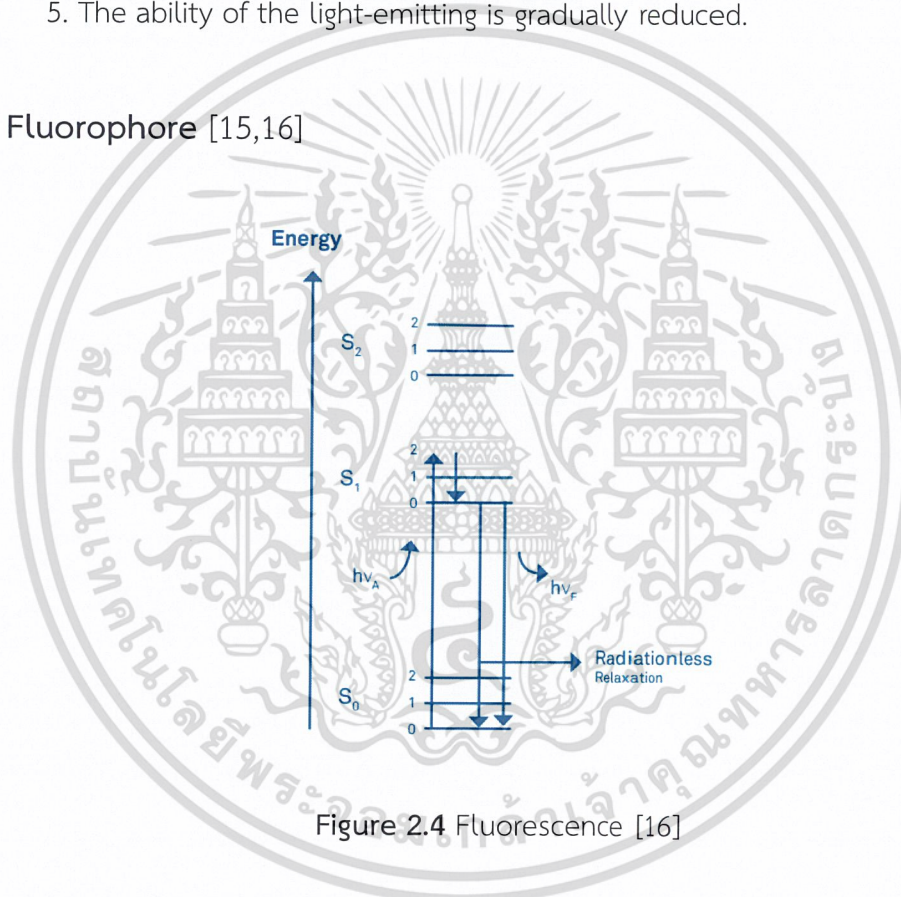


Figure 2.4 Fluorescence [16]

Fluorophores are fluorescent chemical compounds that can re-emit light upon light excitation occur because of a light source. Typically these compounds get this property due to the presence of several aromatic groups, which are combined with planar or cyclic molecules with several π bonds (double bonds) [15]. Also, Fluorophores absorb the light of the particular wavelength and then can emit this energy as a longer wavelength. Hence, the emitted light is referred to as fluorescence (Figure 2.4). Furthermore, the wavelength is absorbed by these compounds depend on the chemical structure of the fluorophore, and the intensity of the emitted light is

also directly proportionate to the amount of fluorochrome in the sample. Herein, the absorption of photons in the light ($h\nu_A$) affects an electron which was stimulated from its electronic ground state known as S_0 to an excited state known as S_1 . Every energy state has various vibrational energy levels (such as level 0, 1, 2). While electrons are simulated to the excited state and the photons are emitted to its ground state, having some part dissipated the energy of S_1 through vibration relaxation. For the reason that the wavelength of the light-emitting ($h\nu_F$) is always longer than that of the exciting light and the energy of the emitting photons is low thus the wavelength is longer. Although the exciting and emitting wavelengths are overlapping because of a fluorophore. Then, this phenomenon is called the Stokes shift [16].

2.3 Chromophore [17,18,19]

A chromophore is the part of an organic molecule responsible for its colour. It is also an expanded delocalized system of a compound which provides its colour. For the colour, which a molecule absorbs wavelengths spectrum of visible light and transmits or reflects others. The chromophore is also a part in a molecule where the balance of the different energy between two different molecular orbitals falls within the range of the visible spectrum. Visible light can react with the chromophore, the results can thus be absorbed by exciting an electron from its ground state into an excited state [17]. In a particular, chromophores undergo a modification of the molecule as appears in the fluorophore and return to the ground state to be the cause of the emission of the colour. So, the excitation wavelengths are in the UV to the visible range and the emitting wavelengths appear in the visible range, providing an individual colour to the molecule, which can see by naked eye [18].

Chromophores are a covalently unsaturated group that demonstrates a characteristic absorption in the visible region. They have comprised of atoms joined in a sequence of alternating single and double bonds. Furthermore, chromophore has two types of chromophore systems are independent chromophores and dependent chromophores. Independent chromophores, which involve both π electrons and n (non-bonding) electrons undergo n to π^* and π to π^* transitions such as an azo group.

Dependent chromophores in which comprise π electrons and undergo π to π^* transitions such as ethylene. Moreover, a conjugated π -system of

chromophore affects the absorption of the compound, for instance, the number of double bonds of the system rises, the wavelength of light absorbed by the smallest part also rises [19].

2.4 Chemicals

2.4.1 Phenothiazine

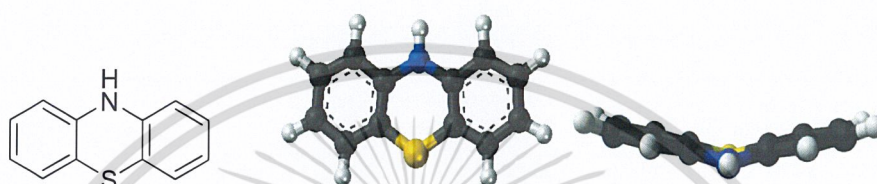


Figure 2.5 Chemical structure of Phenothiazine [20]

Phenothiazine (PTZ) is a tricyclic aromatic ring with sulfur and nitrogen atoms (Figure 2.4). This molecule has a folded configuration with the dihedral angle between the two planes of the benzene rings. Its molecular formula is $C_{12}H_9NS$. Molecular weight is 199.27 g/mol. Phenothiazine involves an additional electron-rich sulfur atom, which illustrates very good hole transport capability. Furthermore, phenothiazine has a strong electron-donating ability because of the different C - N and C - S bond length of PTZ. And the structure of phenothiazine has electroluminescence property and prevent overlapping of molecules [21, 22].

Properties [21]

1. Phenothiazine is a light yellow crystalline solid.
2. PTZ is rhombic leaflets or diamond-shaped structure.
3. It is almost insoluble in water but also slightly miscible in most of the common organic solvents such as ethanol.
4. It is simply oxidized, particularly in the presence of sunlight and the slightest traces of moisture.
5. Density is 1.34 g/cm³
6. Melting point is 185°C
7. Boiling point is 371°C

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ไม่ว่ากรณีใดๆ ผู้ที่นำเอกสารนี้ไปใช้โดยไม่ขออนุญาตเจ้าของเอกสารทุกครั้งที่มีการนำไปใช้

Applications [21]

1. Phenothiazine is widely used anthelmintic reagent with excellent efficiency in treating.
2. Phenothiazine is the intermediates of good chemicals such as dyes and drugs by itself being an adjuvant material for synthetic material.
3. It is mainly used as the polymerization inhibitor for acrylic acid, acrylic esters, and methacrylic acid as well as an ester monomer.

2.4.2 Pyrene

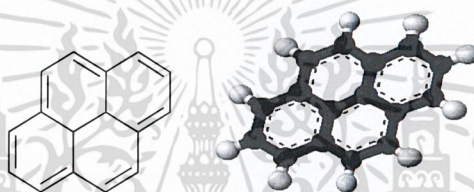


Figure 2.6 Chemical structure of Pyrene [23]

Pyrene is the smallest polycyclic aromatic hydrocarbon (PAHs) family and is obtained during the combustion of organic compounds. Pyrene is a kind of solid aromatic compound with its molecule comprising of four aromatic condensed planar structure (Figure 2.5). Its molecular formula is $C_{16}H_{10}$ and its molecular weight is 202.26 g/mol. Pyrene is a promising chromophore by having a higher fluorescent quantum yield and its good light-emitting properties. Moreover, pyrene has very good thermal and chemical stability [24,25].

Physical properties [24]

1. Pyrene appears as pale yellow crystalline monoclinic tablets.
2. It is immiscible in water and easily miscible in benzene, toluene, carbon disulfide, ether and other organic solvents.
3. It is carcinogenic.
4. Density is 1.271 g/cm^3
5. Melting point is $148 \text{ }^\circ\text{C}$

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6. Boiling point is 393 °C

Applications [24]

1. It can be used as raw material for organic synthesis.
2. It can be applied to dyes, synthetic resins and plastics, such as pyranine.
3. The derivative of pyrene is used for a fluorescence probe in fluorescence spectroscopy which has a long service time and as a probe to examine the solvent in ambient condition.

2.5 Extraction [26]

Extraction is the first step to separate the desired compounds, which is a key step in conveying to the reaction and isolating the compounds instantaneously thereafter the reaction has completed. The solutions of the sample are added to the separatory funnel to either extract or wash the samples and then isolate the desired compounds from excess reagents, catalysts, solvents, or materials formed from side reactions.

2.5.1 Solvent extraction [26]

Solvent extraction, also known as liquid-liquid extraction and partitioning, is a separation method of a liquid mixture of compounds in which a solution is transferred from one phase into another because of the different solubility of compounds in two different immiscible liquids. A liquid-liquid extraction consists of two immiscible liquids, including aqueous phase and an organic phase. Also, the two layers must not dissolve in each other. In practice, two insoluble liquids are placed in the separatory funnel and then two layers are shaken with two immiscible solvents for washing. The materials to be analyzed is more miscible in one than the other. For example, the desired organic compounds dissolve in organic layers and remove residual impurities such as acids, bases and salts in an aqueous phase. Furthermore, the liquid-liquid extraction needs to be based on their relative solubility in two immiscible liquids, and distributes between the two solvents according to chemical properties and mainly polarity. The principle of this technique is the like dissolves like.

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2.6 Separation [27]

Separation techniques are used to isolate mixtures into its component of the compounds. The mixtures contain compounds which are not chemically combined. Moreover, the separation depends on the solvent system which is important for separation. It should select properly. Particularly, the polarity of the solvents.

2.6.1 Thin-layer chromatography (TLC) [29]

Thin-layer chromatography (TLC) is a very common technique in synthetic chemistry for recognizing compounds, deciding its purity and observing the advancement of a reaction. TLC is a cheap, quick and easy technique, which is used to isolate the components of a mixture into its compounds. In the process of thin-layer chromatography (TLC), the substances are divided which are diffused between two phases, one of that is the stationary phase and the other is the mobile phase. The mixture of substances is spotted on a glass plate coated with a very thin layer of adsorbent material, normally silica gel or alumina. Thin-layer chromatography is thus based on the principle of adsorption chromatography, depending on the adsorbent, its treatment and nature of solvents. Also, the separation depends on the relative affinity of compounds approaches both the phases. The compounds move along with the mobile phase through the stationary phase and separate. According to the polarity and the degree of adhesion of each component on the stationary phase. The compounds which have a higher polarity, they would have high affinity to the stationary phase and transfer moderately during the other substances move rapidly. More importantly, a solvent system should be the best solvent because TLC is often used to decide the best solvent system for column chromatography. The ideal solvent system is simply the system that provides the best separation. Therefore, the separation of the mixture is accomplished. The different separation which ascends the TLC plate at different rates, respectively. When the separation is success and the spot would appear at respective levels on the plates. Their individuality are recognized by appropriate detection techniques.

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2.6.2 Column chromatography [28]

Column chromatography is a common technique for purifying compounds, which is used to separate the desired compounds from a mixture dissolved in a fluid. It is a basic method utilized in the purification of compounds based on their polarity. For chromatography process, a mixture of compounds is isolated based on their different sections between a mobile phase and a stationary phase, and depending on the eluent flows down through the column by gravity force or by the application of atmospheric pressure. The principle of column chromatography is based on differential adsorption of compounds to the adsorbent as the compounds flow through the column at different rates which permit them to obtain isolated fractions. This method could be employed on a small scale as well as large scale to purify compounds.

Chromatography involves two phases, which one is the mobile phase and the other one is the stationary phase. The column is prepared by merging the silica with a proper solvent and poured into a column. After that, the mixture to be analyzed is filled onto the top of a column of adsorbents, such as alumina or silica gel. An organic solvent or a mixture compound of the eluent is passed through the column. Compositions of the sample separate from each other by segregation between the stationary phase and the mobile phase. A polarity of the eluent which flows down through the column influences the relative rates at which compounds propel through the column. If the polarity of the eluent matches the polarity of the molecules such as the polar components transfer at a less speed when compared to the non-polar components. Subsequently, the eluent is collected in fractions. Fractions are analyzed by TLC to see if the segregation of the components was successful.

2.7 Literature reviews

2.7.1 S. Xiang, et al. (2019) reported that two new chemical compounds based on phenothiazine, namely 3-(10*H*-phenothiazin-10-yl)-10-phenylacridin-9(10*H*)-one (PTZ-AD) and 2-(10*H*-phenothiazine-10-yl)-10-phenyl-10*H*-phenothiazine-5,5-dioxide (PTZ-2PTO) (Figure 2.6) were successfully designed and synthesized. As a result, the experiment illustrated the thermal decomposition temperature (T_d) of PTZ-2PTO ($T_d=383^\circ\text{C}$) is higher than PTZ-AD ($T_d=345^\circ\text{C}$) gained a 5% weight loss. The glass transition temperatures (T_g) of PTZ-2PTO is 110°C . Meanwhile, no apparent T_g could

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be observed between 50°C and 250°C for PTZ-AD. So that both of chemical compounds are very good morphological stability of PTZ-2PTO and PTZ-AD was convenient for top-grade devices fabrication. Besides, the photoluminescence (PL) spectra of PTZ-2PTO and PTZ-AD in toluene solution, the dual emissions peaks were exhibited around 391, 499 nm and 411, 550 nm, respectively. When compared the nondoped device of PTZ-2PTO and PTZ-AD were demonstrated that the PTZ-AD nondoped device of PTZ-2PTO and PTZ-AD was demonstrated the PTZ-AD nondoped device was nearly the best performance for nondoped yellow TADF-OLEDs because the device exhibited low turn-on voltage of 2.4 V and low-efficiency roll-off was attained. Thus this work provided a new strategy to design TADF materials for highly efficient nondoped OLEDs devices [29].

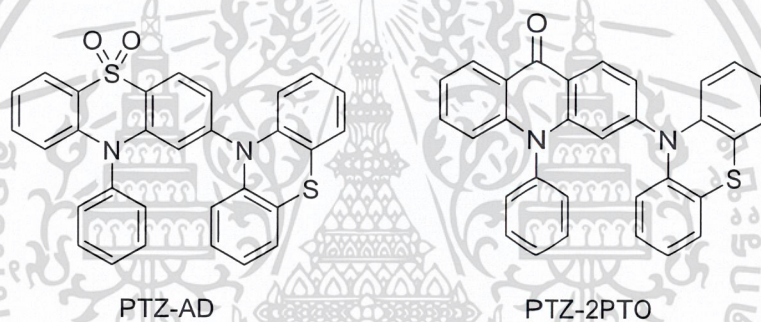
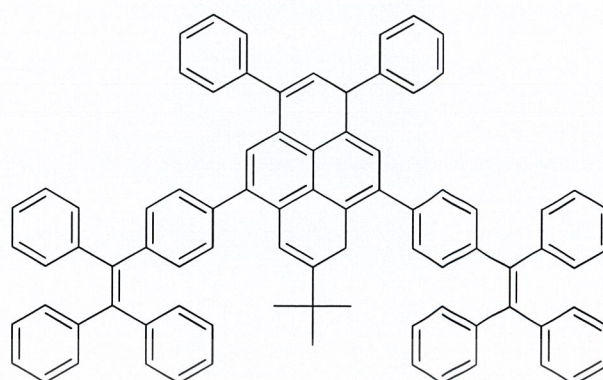


Figure 2.7 Chemical structures of PTZ-AD and PTZ-2PTO

2.7.2 X. Yang, et al. (2019) reported that two new chemical compounds based on pyrene butterfly-shaped called AIEgens, 7-tert-butyl-1,3-diphenyl-5,9-bis(4-(1,2,2-triphenylvinyl)phenyl)pyrene (Py(5,9)BTPE) and 7-tert-butyl-1,3-diphenyl-5,9-bis(1,2,2-triphenylvinyl)pyrene (Py(5,9)BTriPE) (Figure 2.7) were successfully designed and synthesized. Both of chemical compounds demonstrated high thermal stability and glassiness property with high T_g . The devices illuminated a sky-blue and a pure-blue EL with CIE coordinates of (0.19, 0.28) and (0.16, 0.17) for devices of Py(5,9)BTPE and Py(5,9)BTriPE, respectively. A result of the experiment showed that Py(5,9)BTriPE-based device is better EL performances compared with Py(5,9)BTPE-based device with enhanced EQE_{max} : 3.35%, CE_{max} : 6.51 cd/A and PE_{max} : 6.24 lm/W. Furthermore, the EL

emission of the two devices was almost no change with the increasing of the current density from 0.1 to 10 mA cm⁻², indicating their excellent colour stability. [25]



Py(5,9)BTPE



Py(5,9)BTriPE

Figure 2.8 Chemical structures of Py(5,9)BTPE and Py(5,9)BTriPE

2.7.3 S. Sohn, et al. (2019) reported that the organic light-emitting diode materials, namely 1,3,6,8-tetrakis(2,5-dimethylbiphenyl-4-yl)pyrene (BD4PP) (Figure 2.8) was synthesized for pure-blue OLEDs. BD4PP had highly twisted and steric structure for effective fluorescence had high thermal stability of 492°C. Additionally, BD4PP had a wide band gap of ~3 eV as well as CIE diagram y-coordinate < 0.15 for pure-blue fluorescent OLEDs. The BD4PP device doped with BCzVB (Figure 2.8) had the current efficiency of 4.41 cd/A, and external quantum efficiency of 3.80%, which were results of excellent packing density with uniform surface morphology, and to balanced charge carriers. The synthetic BD4PP molecule had a highly twisted and non-coplanar structure because of the steric effect between the pyrene unit and the end group. By

introducing xylene units into the synthetic BD4PP molecule prevented the intermolecular interaction, the resulting in colour purity and high efficiency [30].

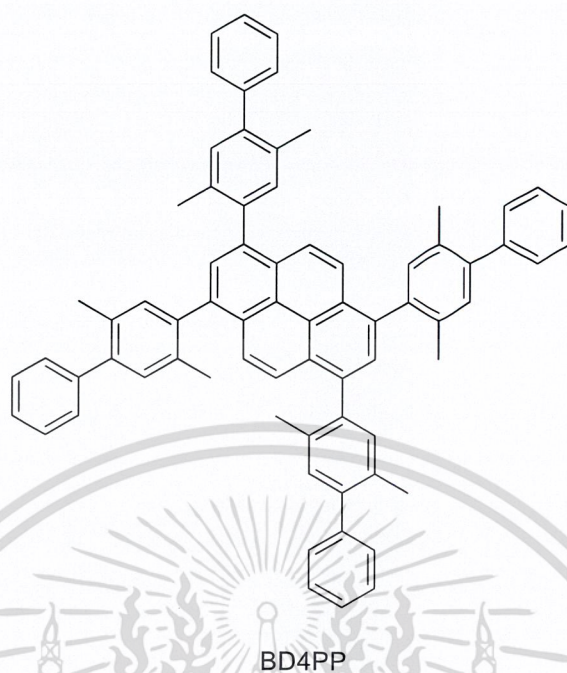


Figure 2.9 Chemical structure of BD4PP

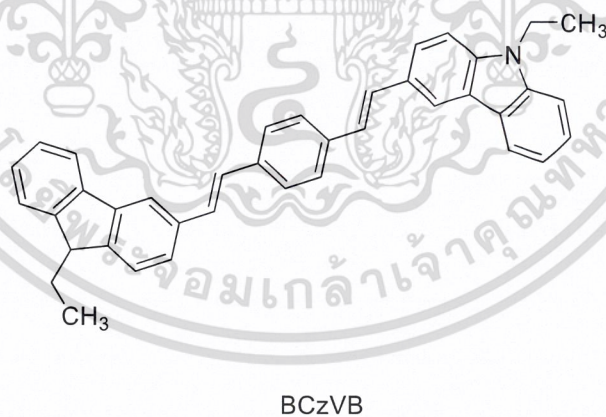


Figure 2.10 Chemical structure of BCzVB

2.7.4 J. Shi, et al. (2020) reported that an efficient blue organic light-emitting diode (BOLED) material, namely 2-phenyl-5-(10-(4-(1,2,2-triphenylvinyl)phenyl)-10*H*-phenothiazin-3-yl)-1,3,4-oxadiazole (TPEPO) (Figure 2.9) was created and synthesized. This compound consisted of phenothiazine and oxadiazole. It remained

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ไม่ว่ากรณีใดๆ ทั้งสิ้น อีกทั้งยังมีเหตุที่แบล็กบอร์ดและเตียงอิงเงาของเอกสารทุกครั้งที่พิมพ์ไว้

to dare to improve blue emitters based on phenothiazine. Thus, the photophysical data revealed an outstanding photoluminescence efficiency of nearly 60% in the nondoped evaporated films. The device exhibited a low turn-on voltage of 4.0 V, which was reported at a luminance of 1 cd m^{-2} . The TPEPO-based nondoped device exhibited a maximum luminance of 17007 cd m^{-2} , the current efficiency of 15.86 cd A^{-1} , the power efficiency of 10.90 lm W^{-1} . The TPEPO device also demonstrated a strong blue emission at 484 nm. The EQE of the nondoped TPED device is 6.62% and radiative exciton ratio was nearly 55%. This research provided a new concept for the design of a new generation of blue chromophores with phenothiazine as the donor [22].

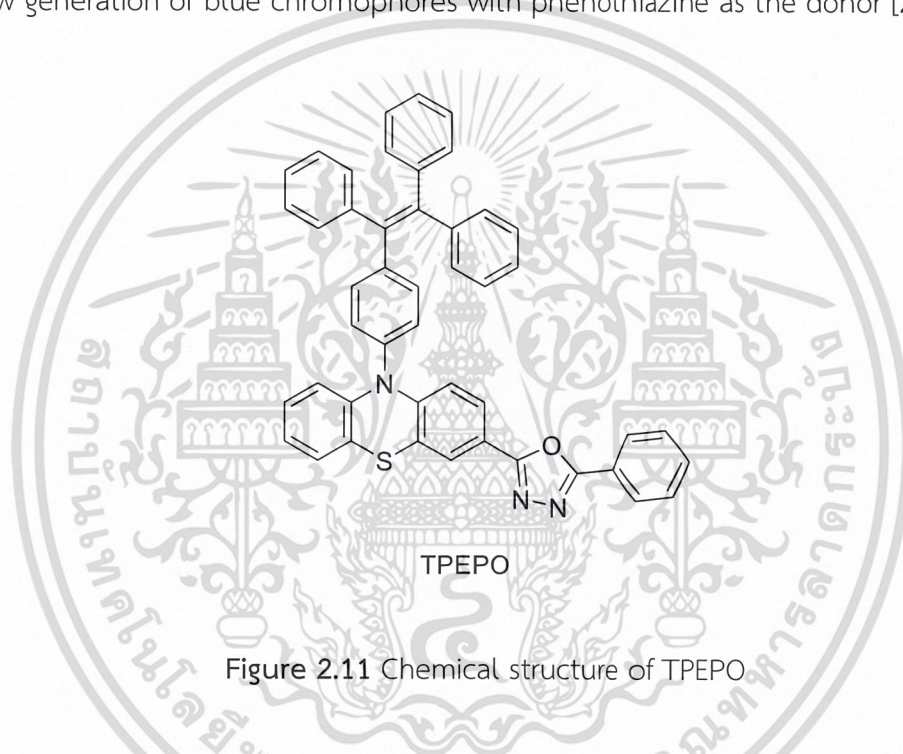
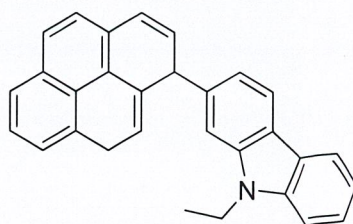


Figure 2.11 Chemical structure of TPEPO

2.7.5 T. Zhang et al. (2020) reported that 2-(pyren-1-yl)-N-ethylcarbazole (PyEtCz) (Figure 2.10) was created and synthesized as a new fluorescent material based on carbazole-pyrene hybrid with deep blue emission. The device based on PyEtCz illustrated strong deep-blue emission with a unique emission at 452 nm, and a CIE colour coordinate of (0.15, 0.10). The device had a low turn-on voltage at 3.7 V. The material showed good thermal stability. PyEtCz possessed the high HOMO level of -5.48 eV and the LUMO level of -2.42 eV as well as high solution fluorescence quantum yield. The non-doped OLEDs used PyEtCz to be as an emitter showed the fantastic performances with the maximum the external quantum efficiency of 3.35%, good performance with a maximum luminance of 6573 cd m^{-2} , and maximum luminance

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efficiency of 3.24 cd/A. The results were expected to contribute to the development of a new deep blue fluorescent material [31].



PyEtCz

Figure 2.12 Chemical structure of PyEtCz



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CHAPTER 3

Research methodology

3.1 Chemicals and materials

- 3.1.1 Phenothiazine (>98%): Tokyo chemical industry Co., Ltd
- 3.1.2 1-Bromooctane (>98%): Fluka Chemical Co., Ltd
- 3.1.3 Benzyl bromide (98%): ACROS ORGANIC Co., Ltd
- 3.1.4 Hexane (GR/AR/ACS GRADE): DUKSAN PURE CHEMICALS Co., Ltd
- 3.1.5 Dichloromethane (GR GRADE): DUKSAN PURE CHEMICALS Co., Ltd
- 3.1.6 Acetone (GR GRADE): DUKSAN PURE CHEMICALS Co., Ltd
- 3.1.7 Ethyl Acetate (GR GRADE): DUKSAN PURE CHEMICALS Co., Ltd
- 3.1.8 Dimethyl sulfoxide (Analytical grade): Fisher Scientific Co.
- 3.1.9 Potassium hydroxide (Reagent grade): Lab-scan Co., Ltd
- 3.1.10 Sodium sulfate anhydrous (Laboratory reagent grade): Fisher Scientific, Co.
- 3.1.11 Distilled water
- 3.1.12 Silica gel
- 3.1.13 Methanol (GR GRADE): DUKSAN PURE CHEMICALS Co., Ltd
- 3.1.14 Chloroform (Analytical grade): CARLO ERBA Reagents Co., Ltd
- 3.1.15 *N*-Bromosuccinimide (97%): SIGMA-ALDRICH, Co.
- 3.1.16 Potassium carbonate (Reagent grade): Fisher Scientific, Co.
- 3.1.17 Toluene (Analytical grade): RCI Labscan, Co., Ltd
- 3.1.18 Tetrakis(triphenylphosphine)palladium(0) (99%) (Reagent grade): SIGMA-ALDRICH, Co.
- 3.1.19 1-Pyreneboronic acid (Laboratory grade) : Tokyo chemical industry Co., Ltd
- 3.1.20 Toluene (Analytical grade): RCI Labscan, Co., Ltd
- 3.1.21 Ethanol : DUKSAN PURE CHEMICALS Co., Ltd

3.2 Apparatus

3.2.1 Round-bottomed flask

3.2.2 Two-neck round-bottomed flask

3.2.3 Erlenmeyer flask

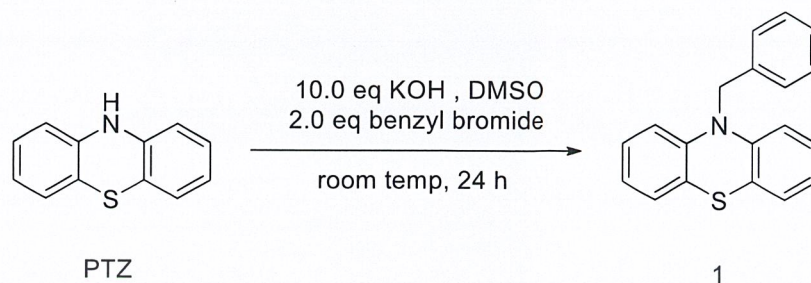
เอกสารนี้เป็นเอกสารที่สงวนไว้สำหรับการใช้งานเพื่อการศึกษาเท่านั้น ไม่อนุญาตให้นำไปใช้ประโยชน์ด้านการค้า
ไม่ว่ากรณีใดก็ตาม หากมีให้ตัดแปลงเนื้อหาและต้องอ้างอิงถึงเจ้าของเอกสารทุกครั้งที่มีการนำไปใช้

- 3.2.4. Beaker
- 3.2.5 Separatory funnel
- 3.2.6 Filtering funnel
- 3.2.7 Pasteur pipette (Dropper)
- 3.2.8 Graduated cylinder
- 3.2.9 Capillary tube
- 3.2.10 Gas inlet
- 3.2.11 Vial
- 3.2.12 Stopper
- 3.2.13 Magnetic bar
- 3.2.14 Aluminium foil
- 3.2.15 TLC Silica gel
- 3.2.16 Cotton
- 3.2.17 Stirring rod
- 3.2.18 Hotplate Stirrer
- 3.2.19 Rotary Evaporator
- 3.2.20 Column
- 3.2.21 Nuclear Magnetic Resonance (NMR) spectrometer (500 MHz)
- 3.2.22 Parafilm
- 3.2.23 Pestle & Mortar
- 3.2.24 Condenser
- 3.2.25 Thermometer
- 3.2.26 Forceps
- 3.2.27 Spatula
- 3.2.28 Rotary Evaporator Bump Trap
- 3.2.29 T-shape stopcock way vacuum
- 3.2.30 Vacuum pump
- 3.2.31 Thermostat
- 3.2.32 Oil bath
- 3.2.33 Ice bath
- 3.2.34 Buchner funnel
- 3.2.35 Suction flask

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ไม่ว่ากรณีใดๆ ทั้งสิ้น อีกทั้งห้ามมิให้ตัดแปลงเนื้อหาและต้องอ้างอิงถึงเจ้าของเอกสารทุกครั้งที่มีการนำไปใช้

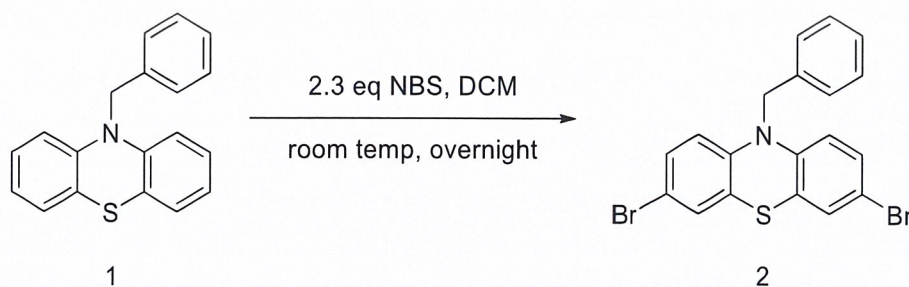
3.3 Method

3.3.1 Synthesis of 10-benzyl-10H-phenothiazine (1)



Phenothiazine (7.0440 g, 35.35 mmol) was dissolved in DMSO (60.0 mL). After that potassium hydroxide (14.1664 g, 252.48 mmol) was slowly added, and then the mixture was stirred for 1 hour at room temperature. Benzyl bromide (8.4 mL, 70.23 mmol) was added drop wise to the reaction mixture, and then the mixture was stirred for 24 hours at room temperature. The reaction mixture was poured into water (60.0 mL) and extracted with dichloromethane (CH_2Cl_2) (60.0 mL x 3). The organic layers were combined and then washed with sat. NaCl (60.0 mL). The organic phase was dried over anhydrous sodium sulfate and then evaporated to dryness under reduced pressure. The crude mixture was purified by silica gel column chromatography using hexane as eluent to provide a colourless solid (7.1355 g, 70% yield). R_f 0.53; IR (ATR): 3026, 2920, 1566, 1458, 1365, 1356, 1256, 1215, 731 cm^{-1} ; $^1\text{H-NMR}$ (acetone- d_6 , 500 MHz, δ /ppm): 7.29-7.37 (m, 4H), 7.21-7.24 (m, 1H), 7.11-7.12 (dd, 2H), 7.00-7.04 (td, 2H), 6.87-6.90 (td, 2H), 6.76-6.78 (dd, 2H), 5.15 (s, 2H).

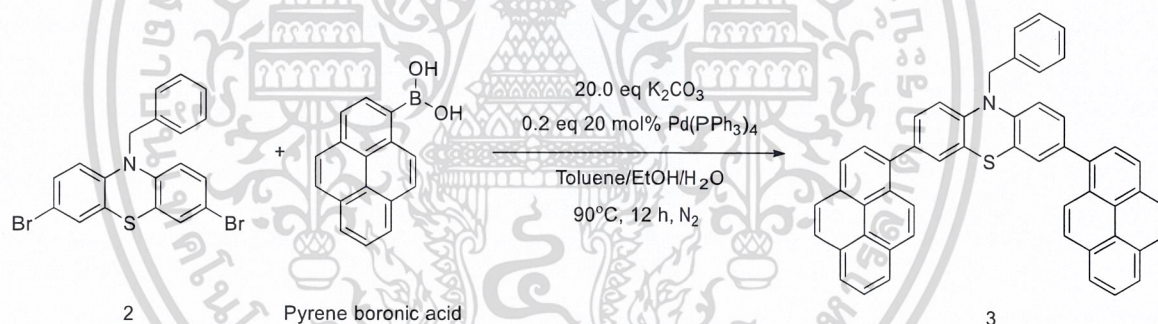
3.3.2 Synthesis of 3,7-dibromo-10-benzyl-10H-phenothiazine (2)



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10-Benzyl-10*H*-phenothiazine (1) (3.5384 g, 12.23 mmol) was dissolved in dichloromethane (210.0 mL) before *N*-bromosuccinimide (NBS) (4.4497 g, 25.00 mmol) was added portion-wise. The reaction mixture was left stirring for overnight at room temperature. The reaction mixture was poured into water (60.0 mL) and extracted with dichloromethane (60.0 mL x 3). The organic layers were combined and then washed with sat. NaCl (60.0 mL). The organic phase was dried over anhydrous sodium sulfate and then evaporated to dryness under reduced pressure. The crude mixture was purified by silica gel column chromatography using hexane as eluent to give a pale yellow solid (3.7601 g, 69% yield). R_f 0.52; $^1\text{H-NMR}$ (CDCl_3 , 500 MHz, δ /ppm): 7.33-7.36 (t, 1H), 7.24-7.29 (m, 2H), 7.18-7.19 (d, 2H), 7.06-7.08 (dd, 4H), 6.46-6.48 (d, 2H), 5.02 (s, 2H).

3.3.3 Synthesis of 10-benzyl-3,7-di(pyren-1-yl)-10*H*-phenothiazine (BDPy-PTZ, 3)



To a mixture of 3,7-dibromo-10-benzyl-10*H*-phenothiazine (2) (0.5173 g, 1.16 mmol), pyrene boronic acid (1.3730 g, 5.58 mmol), potassium carbonate (3.1903 g, 23.08 mmol) and tetrakis(triphenylphosphine)palladium (0) (0.2510 g, 0.22 mmol) in a two-neck flask under a nitrogen atmosphere, a solution mixture of toluene (20.0 mL), ethanol (5.0 mL) and H_2O (5.0 mL) was added at room temperature. The mixture was stirred at 90°C for 12 hours. The reaction mixture was poured into water (60.0 mL) and extracted with dichloromethane (60.0 mL x 3). The organic layers were combined and then washed with sat. NaCl (60.0 mL). The organic phase was dried over anhydrous sodium sulfate and then evaporated under reduced pressure. The crude mixture was triturated with CH_2Cl_2 and the filtrate was then subjected to purify by silica gel column chromatography using a mixture of hexane and CH_2Cl_2 (98:2, 96:4, 94:6, 92:8, 90:10,

v/v, respectively) as eluent and then recrystallized from dichloromethane/hexane (1:2, v/v) to afford a yellow solid (0.3271 g, 41%yield). R_f 0.28; IR (ATR): 3032, 1584, 1474, 1385, 1357, 1261, 1215, 845, 725 cm^{-1} ; $^1\text{H-NMR}$ (acetone- d_6 , 500 MHz, δ/ppm): 8.34 (d, 2H), 8.27-8.32 (dd, 4H), 8.24 (d, 2H), 8.20 (s, 4H), 8.18 (d, 2H), 8.07-8.09 (t, 2H), 8.03 (d, 2H), 7.58 (d, 2H), 7.45-7.48 (m, 4H), 7.40-7.42 (d, 2H), 7.33-7.36 (t, 1H), 7.10-7.12 (d, 2H), 5.47 (s, 2H).

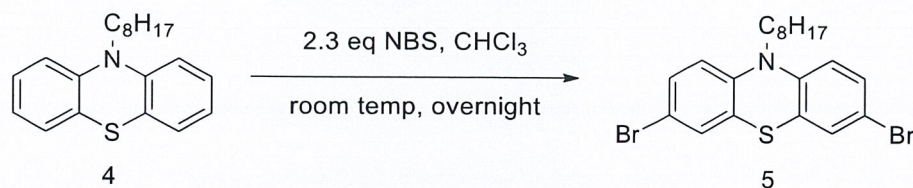
3.3.4 Synthesis of 10-octyl-10H-phenothiazine (4)



Phenothiazine (4.0080 g, 20.11 mmol) was dissolved in dimethyl sulfoxide (DMSO) (30.0 mL). After that potassium hydroxide (8.0685 g, 143.79 mmol) was slowly added, and then the mixture was stirred for 1 hour at room temperature. Octyl bromide (5.6 mL, 31.89 mmol) was added drop wise to the reaction mixture, and then the mixture was stirred for 24 hours at room temperature. The reaction mixture was poured into water (60.0 mL) and extracted with dichloromethane (60.0 mL x 3). The organic layers were combined and then washed with sat. NaCl (60.0 mL). The organic phase was dried over anhydrous sodium sulfate and then evaporated to dryness under reduced pressure. The crude mixture was purified by silica gel column chromatography using hexane as eluent to give the product as a pale yellow oil (5.3500 g, 86%yield). R_f 0.79; IR (ATR): 3063, 2922, 1593, 1456, 1332, 1284, 1247, 742 cm^{-1} ; $^1\text{H-NMR}$ (acetone- d_6 , 500 MHz, δ/ppm): 7.12-7.20 (m, 4H), 7.05-6.92 (m, 4H), 3.93-3.96 (t, 2H), 1.76-1.86 (m, 2H), 1.23-1.48 (m, 10H), 0.81-0.88 (t, 3H).

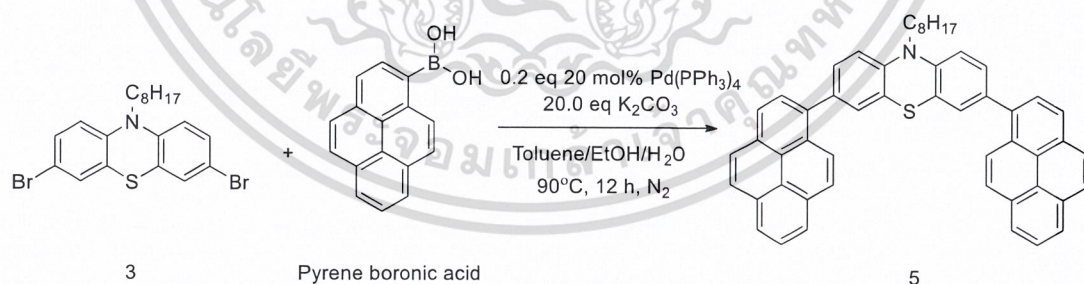
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3.3.5 Synthesis of 3,7-dibromo-10-octyl-10*H*-phenothiazine (5)



10-Octyl-10*H*-phenothiazine (4) (3.0267 g, 9.72 mmol) was dissolved in chloroform (CHCl₃) (60.0 mL) and cooled to 5-10 °C with an ice bath. After that *N*-bromosuccinimide (NBS) of 4.0859 g (22.96 mmol) was added slowly. The mixture was stirred for overnight at room temperature. The reaction mixture was poured into water (60.0 mL) and extracted with dichloromethane (60.0 mL × 3). The organic layers were combined and then washed with sat. NaCl (60.0 mL). The organic phase was dried over anhydrous sodium sulfate and then evaporated to dryness under reduced pressure. The crude mixture was purified by silica gel column chromatography using hexane as eluent to yield a yellow oil (2.4670 g, 54% yield). *R*_f 0.81; ¹H-NMR (CDCl₃, 500 MHz, δ/ppm): 7.19-7.26 (dd, 4H), 6.65-6.67 (d, 2H), 3.37 (t, 2H), 1.70-1.76 (m, 2H), 1.25-1.40 (m, 10H), 0.87-0.89 (t, 3H).

3.3.6 Synthesis of 10-octyl-3,7-di(pyren-1-yl)-10*H*-phenothiazine (ODPy-PTZ, 6)



To a mixture of 3,7-dibromo-10-octyl-10*H*-phenothiazine (3) (0.2145 g, 0.46 mmol), pyrene boronic acid (0.5423 g, 2.20 mmol), potassium carbonate (1.1981 g, 8.67 mmol) and tetrakis(triphenylphosphine)palladium (0.1514 g, 0.13 mmol) in a two-neck flask under a nitrogen atmosphere, a solution mixture of toluene (16.0 mL), ethanol (4.0 mL) and H₂O (4.0 mL) was added at room temperature. The mixture was stirred at 90 °C for 12 hours. The reaction mixture was poured into water (60.0 mL) and extracted

with dichloromethane (60.0 mL x 3). The organic layers were combined and then washed with sat. NaCl (60.0 mL). The organic phase was dried over anhydrous sodium sulfate and then evaporated under reduced pressure. The crude mixture was triturated with CH_2Cl_2 and the filtrate was then subjected to purify by silica gel column chromatography using a mixture of hexane and CH_2Cl_2 as eluent. However, the desired product could not be obtained.



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CHAPTER 4

Results and Discussion

4.1 Synthesis of dipyrene-phenothiazine derivatives

Herein, we reported the design and synthesis of phenothiazine derivative substituted with pyrene, namely 10-benzyl-3,7-di(pyren-1-yl)-10*H*-phenothiazine (BDPy-PTZ) and 10-octyl-3,7-di(pyren-1-yl)-10*H*-phenothiazine (ODPy-PTZ).

4.1.1 Synthesis of 10-benzyl-3,7-di(pyren-1-yl)-10*H*-phenothiazine (BDPy-PTZ)

The chemical structure and the retrosynthetic analysis of BDPy-PTZ were demonstrated in Figure 4.1. BDPy-PTZ could be synthesized through Suzuki-Miyaura cross-coupling reaction between 3,7-dibromo-10-benzyl-10*H*-phenothiazine (**1**) and pyrene boronic acid (**3**). Compound **1** could be prepared from the corresponding PTZ by using alkylation with benzyl bromide, followed by bromination by NBS. Furthermore, 3,7-dibromo-10-benzyl-10*H*-phenothiazine and 10-benzyl-10*H*-phenothiazine could be prepared by bromination and alkylation reactions, respectively (Figure 4.1).

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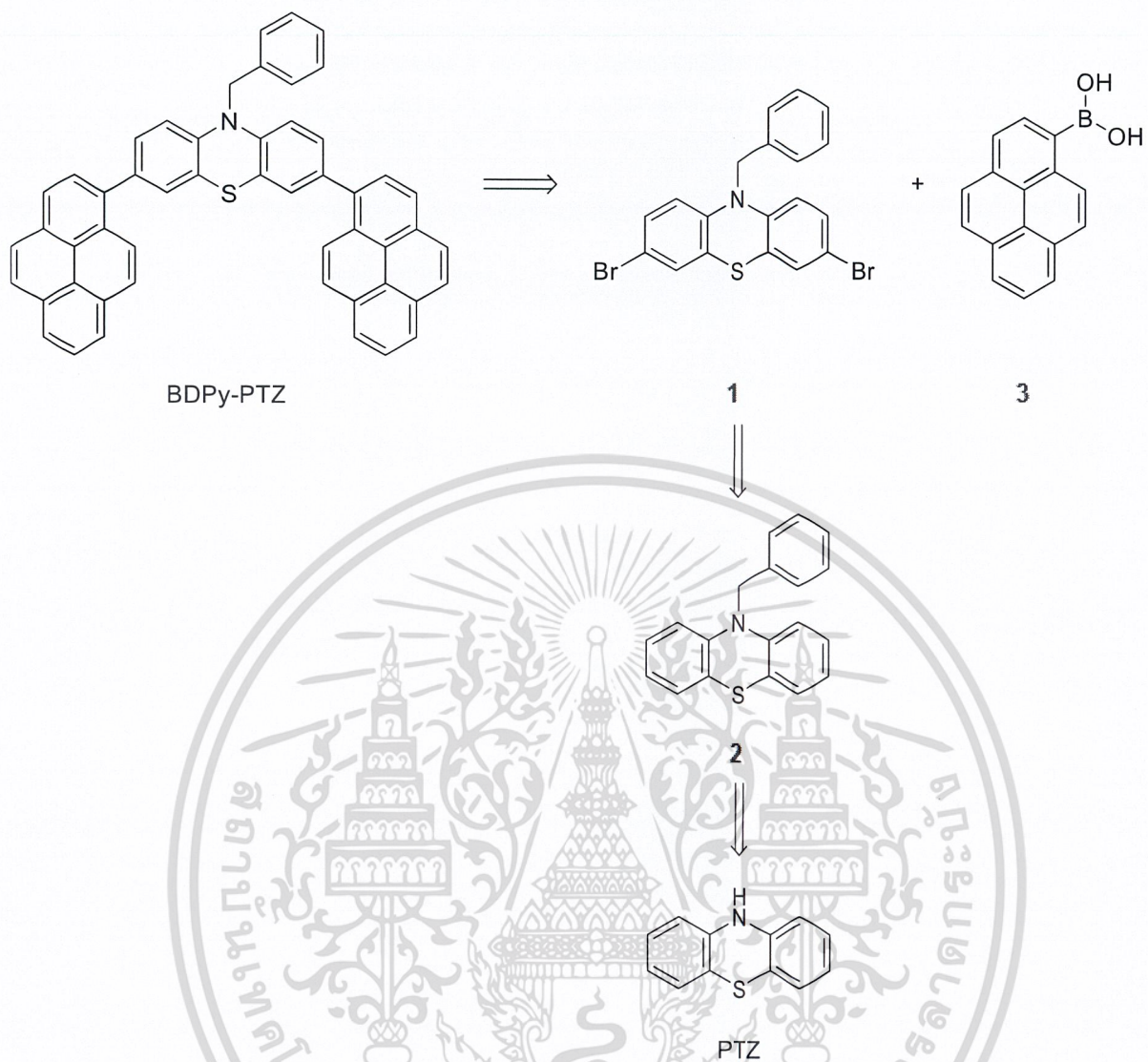


Figure 4.1 Retrosynthesis of BDPy-PTZ

The synthetic routes of the intermediates and the target compound were displayed in Figure 4.2. PTZ was subjected to react with benzyl bromide under a basic condition to provide compound **2** in 70%. Compound **2** was then treated with *N*-bromosuccinimide (NBS) to yield compound **1** in 69%. Finally, compound **1** underwent Suzuki-Miyaura cross-coupling reaction with pyrene boronic acid in the presence of a catalytic amount of $\text{Pd}(\text{PPh}_3)_4$ and K_2CO_3 in a solvent mixture of toluene: EtOH: H_2O (8:2:2) at 90 °C for 12 hours to give BDPy-PTZ in 41%.

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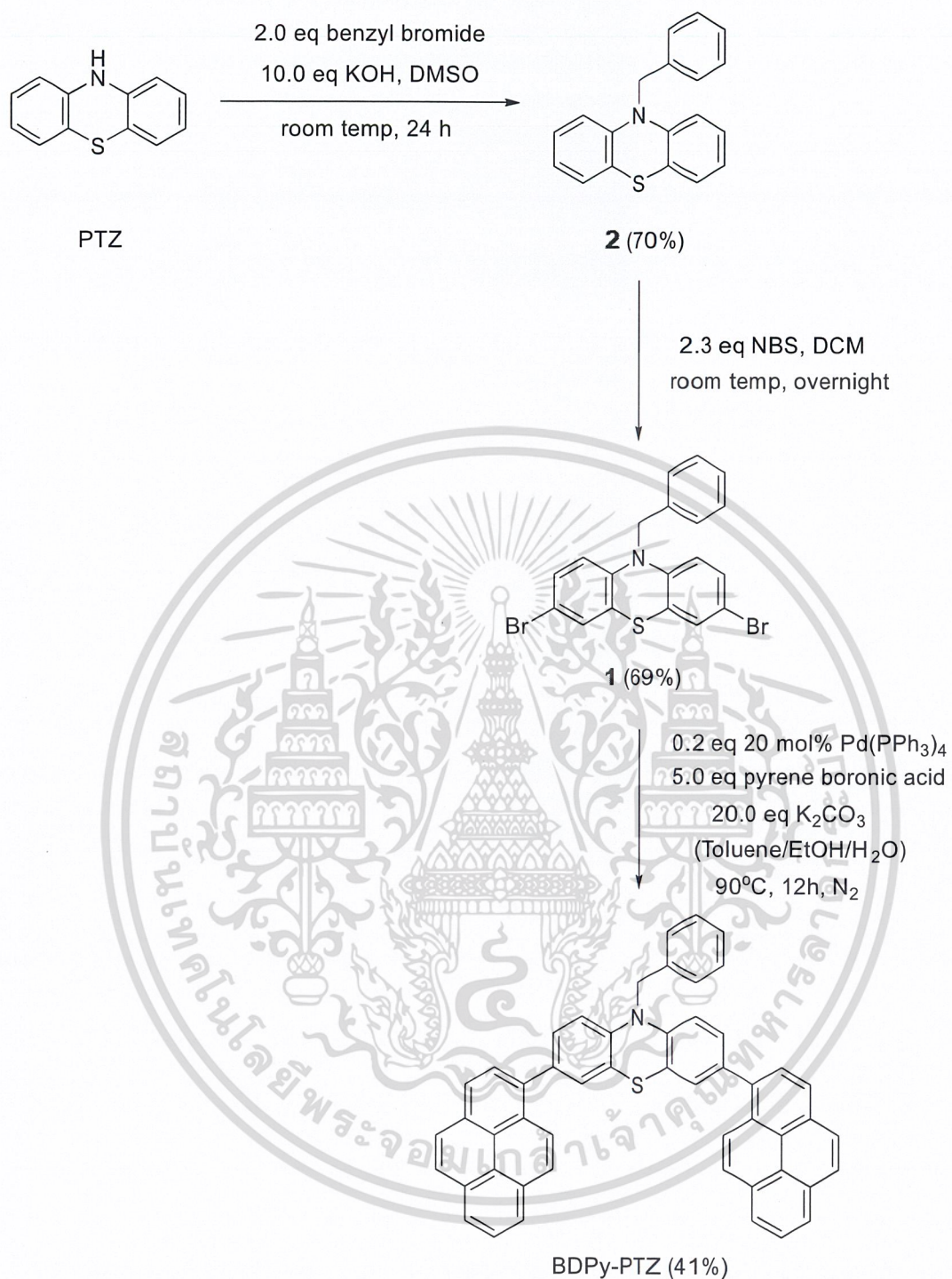


Figure 4.2 Synthetic route of BDPy-PTZ

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4.1.2 Synthesis of 10-octyl-3,7-di(pyren-1-yl)-10*H*-phenothiazine (ODPy-PTZ)

ODPy-PTZ was the last of the target compounds of this research, which consisted of phenothiazine derivative and pyrene derivative as same as BDPy-PTZ but the different substitution was at the *N*-position. The retrosynthesis of ODPy-PTZ was sketched in Figure 4.3. ODPy-PTZ could be synthesized through Suzuki-Miyaura cross-coupling reaction by incorporating 3,7-dibromo-10-octyl-10*H*-phenothiazine (**4**) and pyrene boronic acid (**3**). Compound **4** could be synthesized from PTZ based on alkylation with octyl bromide and bromination, respectively.

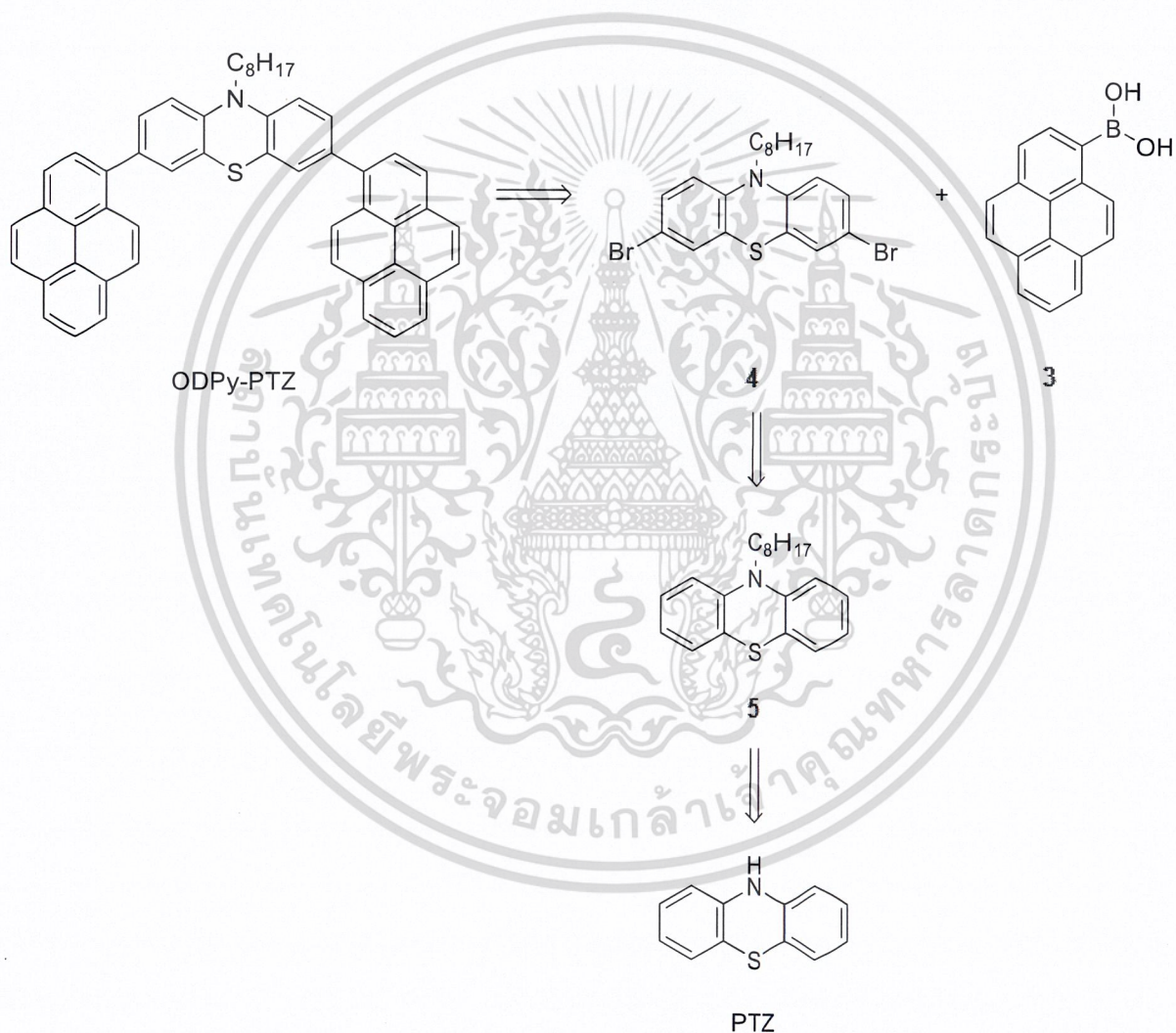


Figure 4.3 Retrosynthesis of ODPy-PTZ

The synthetic procedures for all phenothiazine derivatives were outlined in Figure 4.4. PTZ was subjected to react with octyl bromide under a basic condition to afford compound **5** in 86%. Compound **5** was then treated with *N*-bromosuccinimide (NBS) to give compound **4**

in 54%. Finally, compound **4** was subjected to Suzuki-Miyaura cross-coupling reaction with pyrene boronic acid in the presence of $\text{Pd}(\text{PPh}_3)_4$ and K_2CO_3 in a solvent mixture of toluene: EtOH: H_2O (8:2:2) at 90 °C for 12 hours. However, many attempts to purify the desired product, ODPy-PTZ, was unsuccessful. This was might be an improper solvent system for column chromatography.

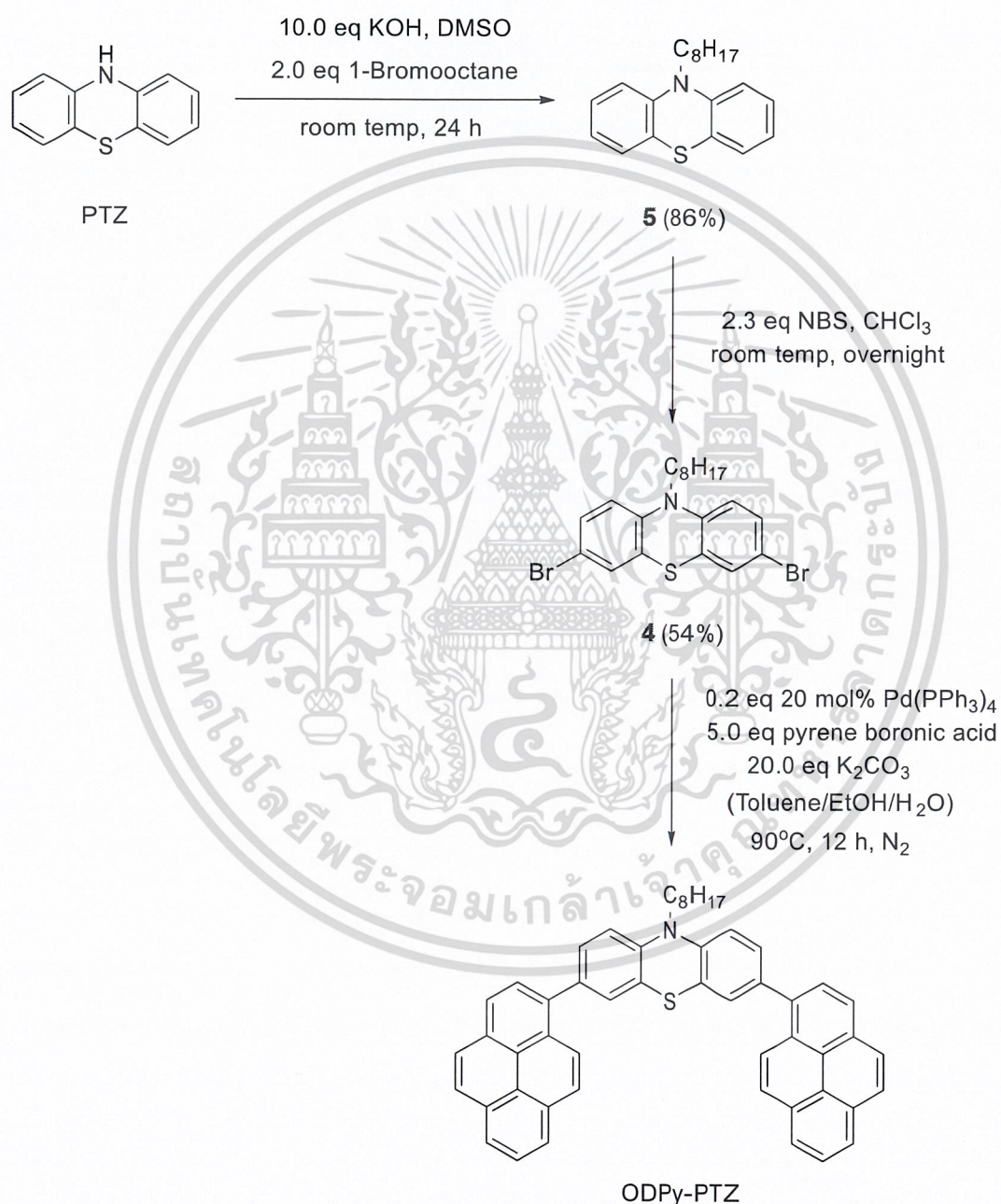


Figure 4.4 Synthetic route of ODPy-PTZ

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CHAPTER 5

Conclusions and Suggestions

5.1 Conclusions

In summary, we have designed two organic compounds for new electroluminescence materials, namely, 10-benzyl-3,7-di(pyrene-1-yl)-10*H*-phenothiazine (BDPy-PTZ) and 10-octyl-3,7-di(pyren-1-yl)-10*H*-phenothiazine (ODPy-PTZ). The synthesis of both target compounds was accomplished by using Suzuki-Miyaura cross-coupling reaction as the key step. Furthermore, all PTZ derivatives were synthesized from phenothiazine *via* alkylation and bromination reactions, respectively, for being the intermediates of the synthetic procedures. At present, only BDPy-PTZ was successfully synthesized and obtained as a yellow solid in 20 %overall yield for 3 steps. For ODPy-PTZ, only a precursor for Suzuki-Miyaura cross-coupling reaction, named 3,7-dibromo-10-octyl-10*H*-phenothiazine, was prepared as a pale yellow oil in 46 %overall yield for 2 steps. Finally, this precursor will be treated with pyrene boronic acid to afford the desired product, ODPy-PTZ.

5.2 Suggestions for the future studies

5.2.1 Suzuki-Miyaura cross-coupling reaction between 3,7-dibromo-10-octyl-10*H*-phenothiazine and pyrene boronic acid will be investigated.

5.2.2 The thermal, optical, and electroluminescent properties of BDPy-PTZ and ODPy-PTZ should be investigated.

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References

- [1] Ràfols-Ribé, J., Will, P.A., Hänisch, C., Gonzalez-Silveira, M., Lenk, S., Rodriguez Viejo, J. and Reineke, S. 2018. “High-performance organic light-emitting—diodes comprising ultrastable glass layers.” *Science Advances*. 4(5): eaar8332.
- [2] Salunke, J. K., F. L., Feron, K., Manzhos, S., Lo, M. F., Shinde, D., Patil, A., Lee, C. S., Roy, V. A., Sonar, P. and Wadgaonkar, P. P. 2016. “Phenothiazine and carbazole substituted pyrene based electroluminescent organic semiconductors for OLED devices.” *Journal of Materials Chemistry C*. 4(5): 1009-1018.
- [3] Tang, C. W. and VanSlyke, S. A. 1987. “Organic electroluminescent diodes.” *Applied Physics Letters*. 51(12): 913-915.
- [4] Gustafsson, G., Cao, Y., Treacy, G. M., Klavetter, F., Colaneri, N., and Heeger, A. J. 1992. “Flexible light-emitting diodes made from soluble conducting polymers.” *Nature*. 357(6378): 477-479.
- [5] Kido, J., Hongawa, K., Okuyama, K., and Nagai, K. 1994. “White light-emitting organic electro luminescent devices using the poly(*N*-vinylcarbazole) emitter layer doped with three fluorescent dyes.” *Applied Physics Letters*. 64(7): 815-817.
- [6] Manna, E. 2017. Enhanced light out-coupling of organic light-emitting devices (OLEDs) using novel plastic substrates and improved performance of OLED-based photoluminescence sensing platform. [Online]. Available: <https://lib.dr.iastate.edu/cgi/viewcontent.cgi?article=6367&context=etd>.
- [7] Burrows, P. E., Bulovic, V., Forrest, S. R., Sapochak, L. S., McCarty, D. M., and Thompson, M. E. 1994. “Reliability and -degradation of organic light emitting devices.” *Applied Physics Letters*. 65(23): 2922-2924.
- [8] The Tech-FAQ. 2019. What is Electroluminescence?. [Online]. Available: <https://www.tech-faq.com/what-is-electroluminescence.html>.
- [9] HowStuffWorks. 2019. OLED Components – Electronics. [Online]. Available: <https://electronics.howstuffworks.com/oled1.htm>.
- [10] Karzazi, Y. 2014. “Organic light emitting diodes: Devices and applications.” *Journal of Materials and Environmental Science*. 5(1): 1-12.

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- [11] Vyavahare, O. 2009. Fabrication and characterization of organic light emitting diodes for display applications. [Online]. Available: <https://scholarworks.rit.edu/cgi/viewcontent.cgi?referer=https://www.google.com/&httpsredir=1&article=3763&context=theses>.
- [12] IEEE Web Hosting. 2018. Overview of OLED Display Technology. [Online]. Available: <https://www.https://www.ewh.ieee.org/soc/cpmt/presentations/cpmt0401a.pdf>.
- [13] Ashok Kumar, S., Shankar, J. S., K Periyasamy, B., and Nayak, S. K. 2019. "Device engineering aspects of Organic Light-Emitting Diodes (OLEDs)." *Polymer-Plastics Technology and Materials*. 1-28.
- [14] UKEssays. 2016. Advantages and Disadvantages of Organic Light Emitting Diodes. [Online]. Available: <https://www.ukessays.com/essays/engineering/advantages-and-disadvantages-disadvantages-of-organic-light-emitting-diodes-engineering-essay.php>.
- [15] Difference Between. 2018. Difference Between Fluorophore and Chromophore. [Online]. Available: <https://www.differencebetween.com/difference-between-fluorophore-and-chromophore/>.
- [16] TECHNICAL NOTES BACHEM. 2017. CHROMOPHORES/FLUOROPHORES: SPECTRAL PROPERTIES AND CHARACTERISTIC. [Online]. Available: https://www.bachem.com/fileadmin/user_upload/pdf/Technical_Notes/Chromophors_Fluorophors-Spectral_Properties_and_Fluorophors-Spectral_Properties_and_Characteristics.pdf.
- [17] ResearchGate. 2017. Chromophore-An Utility in UV Spectrophotometer. [Online]. Available: https://www.researchgate.net/publication/296419679_Chromophore_An_Utility_in_UV_Spectrophotometer
- [18] Pediaa.Com. 2017. What is the difference Between Fluorophore and Chromophore. [Online]. Available: <https://pediaa.com/-/what-is-the-difference-between-fluorophore-and-chromophore/>.
- [19] Study.com. 2017. What are Chromophores & Auxochromes?. [Online]. Available: <https://study.com/academy/lesson/what-are-chromophores-auxochromes-definitions-types.html>
- [20] Wikipedia. 2020. Phenothiazine. [Online]. Available: <https://en.wikipedia.org/wiki/Phenothiazine>.
- [21] Chemical Book. 2017. Phenothiazine. [Online]. Available: https://www.chemicalbook.com/ChemicalProductProperty_EN_CB2272320.htm.
- [22] Shi, J., Cui, W., Yu, Y., Lv, X., Xu, L., Lang, W., Sun, Q., Zhang, Y., Xue, S., and Yang, W. 2019. "Highly efficient nondoped blue electroluminescence with an EQE greater than 6.0% based on a phenothiazine donor with hybridized local and charge-transfer excited state." *Dyes and Pigments*. 172: 107860.

- [23] Wikipedia. 2020. Pyrene. [Online]. Available: <https://en.wikipedia.org/wiki/Pyrene>.
- [24] Chemical Book. 2017. Pyrene. [Online]. Available: https://www.chemicalbook.com/ChemicalProductProperty_EN_CB4853011.htm.
- [25] Yang, X., Zhao, Z., Ran, H., Zhang, J., Chen, L., Han, R., Duan, X., Sun, H., and Hu, J. – Y. 2020. “New pyrene-based butterfly-shaped blue AIEgens: Synthesis, structure, aggregation-induced emission and their nondoped blue OLEDs.” *Dyes and Pigments*. 173: 107881.
- [26] Chemistry Libre Texts. 2019. Extraction. [Online]. Available: [https://chem.libretexts.org/Bookshelves/Organic_Chemistry/Book%3A_Organic_Chemistry_Lab_Techniques_\(Nichols\)/04%3A_Extraction](https://chem.libretexts.org/Bookshelves/Organic_Chemistry/Book%3A_Organic_Chemistry_Lab_Techniques_(Nichols)/04%3A_Extraction).
- [27] Chemistry Notes. 2018. Introduction to Separation Techniques. [Online]. Available: <https://chemistrynotesblog.wordpress.com/seperation-techniques/introduction-to-separation-separation-techniques-2/>.
- [28] Principle, procedure, Applications on BYJU’S. 2020. Thin Layer Chromatography (TLC). [Online]. Available: <https://byjus.com/chemistry/thin-layer-chromatography/>.
- [29] Xiang, S., Guo, R., Huang, Z., Lv, X., Sun, S., Chen, H., Zhang, Q., and Wang, L. 2019. “Highly efficient yellow nondoped thermally activated delayed fluorescence OLEDs by utilizing energy transfer between dual conformations based on phenothiazine derivatives.” *Dyes and Pigments*. 170: 107636.
- [30] Sohn, S., Wu, X., Park, K. H., Ahn, H., Jung, S., Kwon, S.-K., and Kim, Y.-H. 2019. “Highly-twisted pyrene derivative for pure-blue organic light emitting diodes.” *Journal of Industrial and Engineering Chemistry*. 78: 239–245.
- [31] Zhang, T., Ye, J., Luo, A., and Liu, D. 2020. “Efficient deep blue emitter based on carbazole-pyrene hybrid for non-doped electroluminescent device.” *Optical Materials*. 100: 109632.

เอกสารนี้เป็นเอกสารที่สงวนไว้สำหรับการใช้งานเพื่อการศึกษาเท่านั้น ไม่อนุญาตให้นำไปใช้ประโยชน์ด้านการค้า
ไม่ว่ากรณีใดๆ ทั้งสิ้น อีกทั้งห้ามมิให้ตัดแปลงเนื้อหาและต้องอ้างอิงถึงเจ้าของเอกสารทุกครั้งที่มีการนำไปใช้



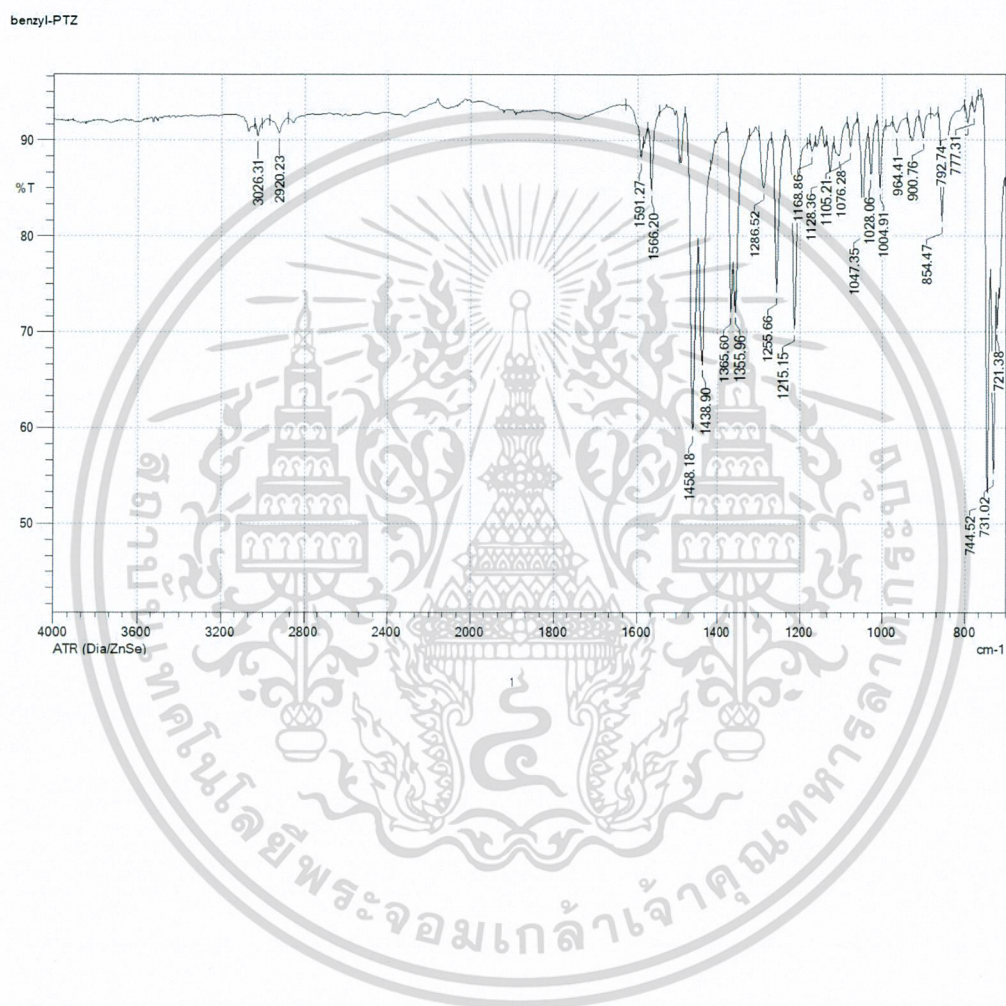
Appendix

เอกสารนี้เป็นเอกสารที่สงวนไว้สำหรับการใช้งานเพื่อการศึกษาเท่านั้น ไม่อนุญาตให้นำไปใช้ประโยชน์ด้านการค้า
ไม่ว่ากรณีใดๆ ทั้งสิ้น อีกทั้งห้ามมิให้ตัดแปลงเนื้อหาและต้องอ้างอิงถึงเจ้าของเอกสารทุกครั้งที่มีการนำไปใช้

Appendix B

Infrared spectra of 10-benzyl-10*H*-phenothiazine, 10-benzyl-3,7-di(pyren-1-yl)-10*H*-phenothiazine (BDPy-PTZ), and 10-octyl-10*H*-phenothiazine

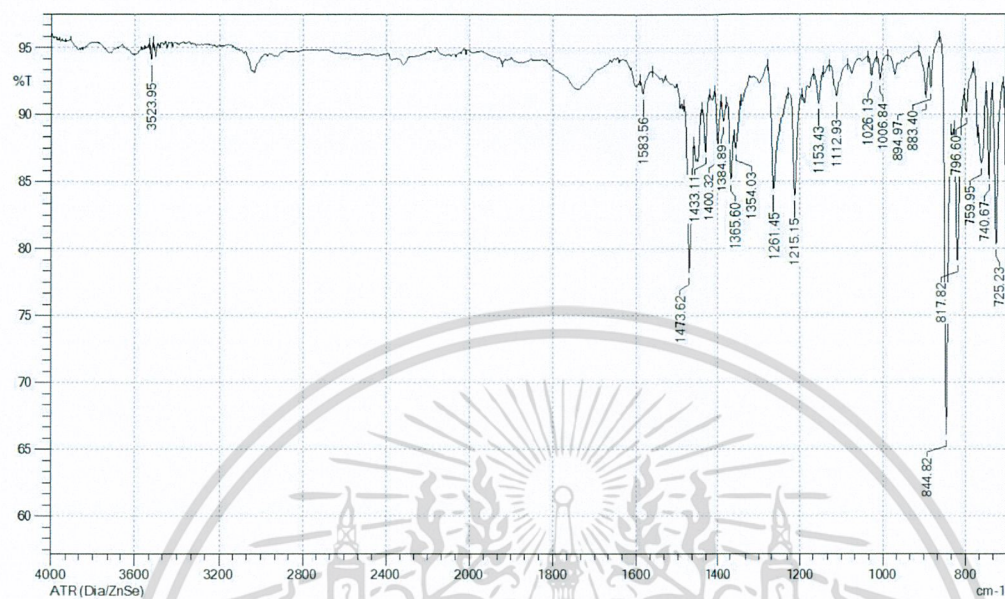
I. IR spectrum of 10-benzyl-10*H*-phenothiazine



เอกสารนี้เป็นเอกสารที่สงวนไว้สำหรับการใช้งานเพื่อการศึกษาเท่านั้น ไม่อนุญาตให้นำไปใช้ประโยชน์ด้านการค้า
ไม่ว่ากรณีใดๆ ทั้งสิ้น อีกทั้งห้ามมิให้ตัดแปลงเนื้อหาและต้องอ้างอิงถึงเจ้าของเอกสารทุกครั้งที่มีการนำไปใช้

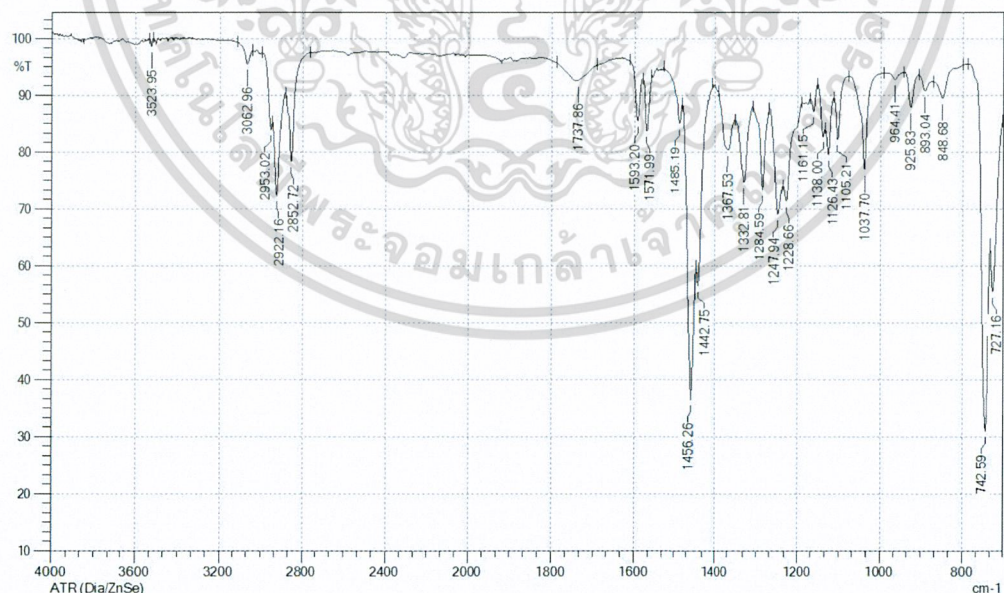
II. IR spectrum of 10-benzyl-3,7-di(pyren-1-yl)-10H-phenothiazine (BDPy-PTZ)

BDPy-PTZ



III. IR spectrum of 10-octyl-10H-phenothiazine

Octyl-PTZ



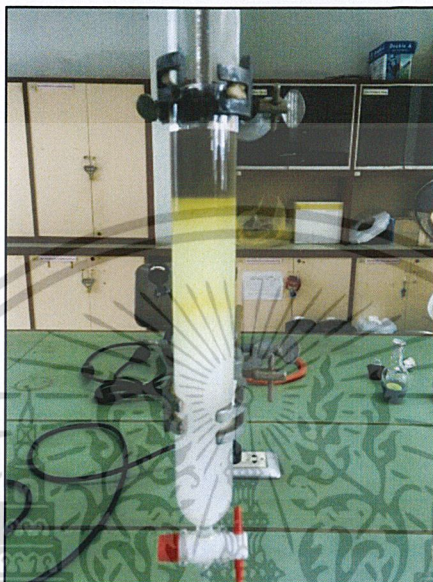
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เอกสารนี้เป็นเอกสารที่สงวนไว้สำหรับการใช้งานเพื่อการศึกษาเท่านั้น ไม่อนุญาตให้นำไปใช้ประโยชน์ด้านการค้า
ไม่ว่ากรณีใดๆ ทั้งสิ้น อีกทั้งห้ามมิให้ตัดแปลงเนื้อหาและต้องอ้างอิงถึงเจ้าของเอกสารทุกครั้งที่มีการนำไปใช้

Appendix C

The synthesis of 10-benzyl-3,7-di(pyren-1-yl)-10*H*-phenothiazine (BDPy-PTZ)

(I) Purification of BDPy-PTZ



(II) The final product



เอกสารนี้เป็นเอกสารที่สงวนไว้สำหรับการใช้งานเพื่อการศึกษาเท่านั้น ไม่อนุญาตให้นำไปใช้ประโยชน์ด้านการค้า
ไม่ว่ากรณีใดๆ ทั้งสิ้น อีกทั้งห้ามมิให้ตัดแปลงเนื้อหาและต้องอ้างอิงถึงเจ้าของเอกสารทุกครั้งที่มีการนำไปใช้