Chapter 5

Synthesis of Diphenol and Activated Aromatic Dihalide Monomers

5.1 Introduction

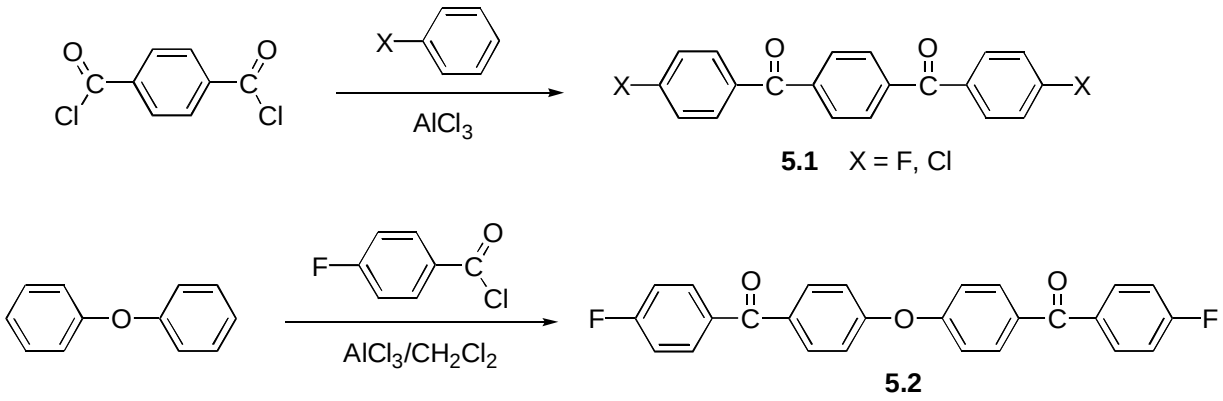
Aromatic polymers containing thermally stable, fully oxidized linkages, such as sulfone, carbonyl and ether groups, are accessible by nucleophilic routes. Different polymer structures can be synthesized from monomers bearing different sequence of the linkages between adjacent aromatic rings. The inherent properties of these polymers, such as crystallinity and thermomechanical properties, depend on the structures of the polymer backbones. One of the critical contributions of the ketone functionality in polymers is the crystallinity which it imbues. This leads to the very desirable property of solvent resistance.[1] It is generally accepted that poly(ether sulfone)s are usually amorphous polymers and subject to attack (swelling or dissolution) by common solvents. However, one of the desirable properties of polymers containing sulfone groups is a high glass transition temperature. Poly(ketone ketone sulfone) (**4.3**) synthesized from aminonitrile precursors has a T_g at 208 °C and a T_m at 458 °C.[2] It would be interesting to study analogous polymers containing sulfone, ketone and ether groups in regular sequences.

For nucleophilic routes, activated difluoro monomers are the main raw materials for the synthesis of high molecular weight PAEKs. They are not readily available in industry.

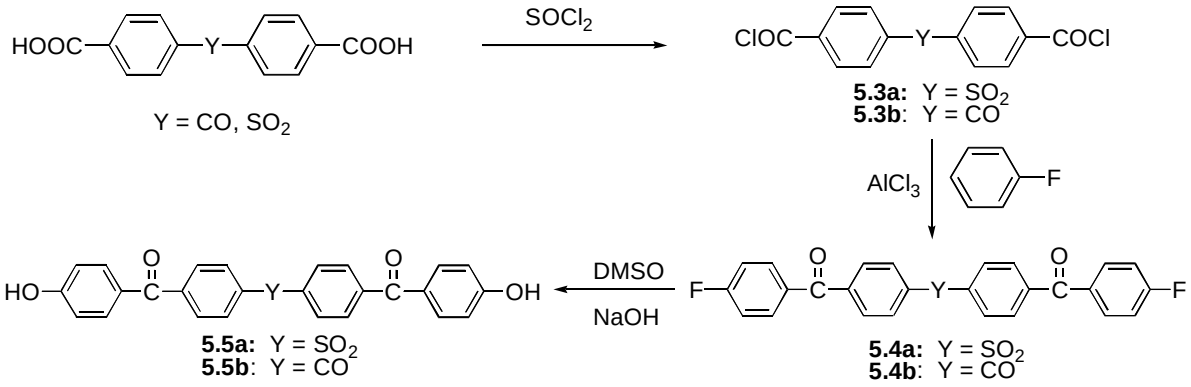
[1] Staniland, P. A. Poly(ether ketone)s. In *Comprehensive Polymer Science*; Allen, G.; Bevington, J. C., Eds.; Pergamon Press: New York, **1989**; Vol. 5, pp 484-497.
[2] Pandya, A.; Yang, J.; Gibson, H. W. *Macromolecules* **1994**, 27, 1367.

They are usually synthesized by Friedel-Crafts processes using fluorobenzene or *p*-fluorobenzoyl chloride (Scheme 5.1).[3,4]

Scheme 5.1



Scheme 5.2

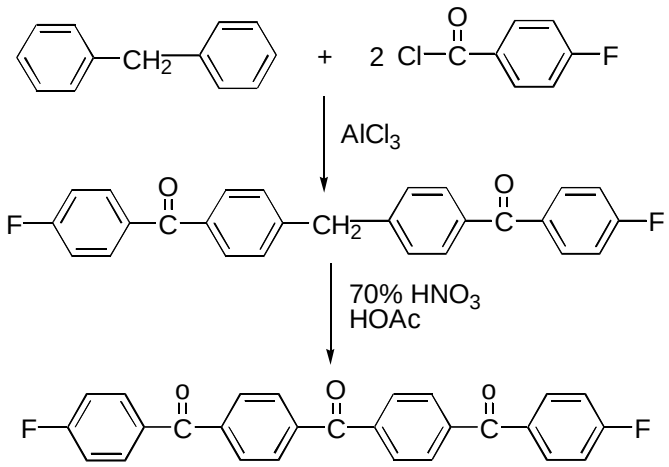


Staniland and coworkers[5] synthesized activated aromatic monomer **5.4a** containing two ketone groups and one sulfone group by Friedel-Crafts acylation reaction of fluorobenzene with aryl acid chloride **5.3a** in 75% overall yield (Scheme 5.2). Similarly, The

[3] Kricheldorf, H. R.; Delius, U.; Tonnes, K. U. *New Polymeric Mater.* **1988**, Vol. 11, No. 2, 127-141.
[4] Hergenrother, P.; Jensen, B.; Havens, S. *Polym. Prepr.* **1985**, 26, 174.
[5] Staniland, P. A.; Wilde, C. J.; Bottino, F. A.; Di Pasquale, G.; Pollicino, A.; Recca, A. *Polymer* **1992**, 33, 1976.

triketone monomer **5.4b** was synthesized in 76% crude yield using 4,4'-benzophenone-dicarboxylic acid and fluorobenzene. This triketone monomer **5.4b** was also synthesized by Friedel-Crafts acylation reaction of 4-fluorobenzoyl chloride with diphenylmethane in methylene chloride, followed by oxidation in 70% HNO_3 (Scheme 5.3). The overall yield was less than 56%. The corresponding diphenol monomers **5.5a** and **5.5b** were obtained by hydrolysis of difluoro monomers **5.4a** and **5.4b** with potassium hydroxide in DMSO in 60-70% yields (scheme 5.2).

Scheme 5.3



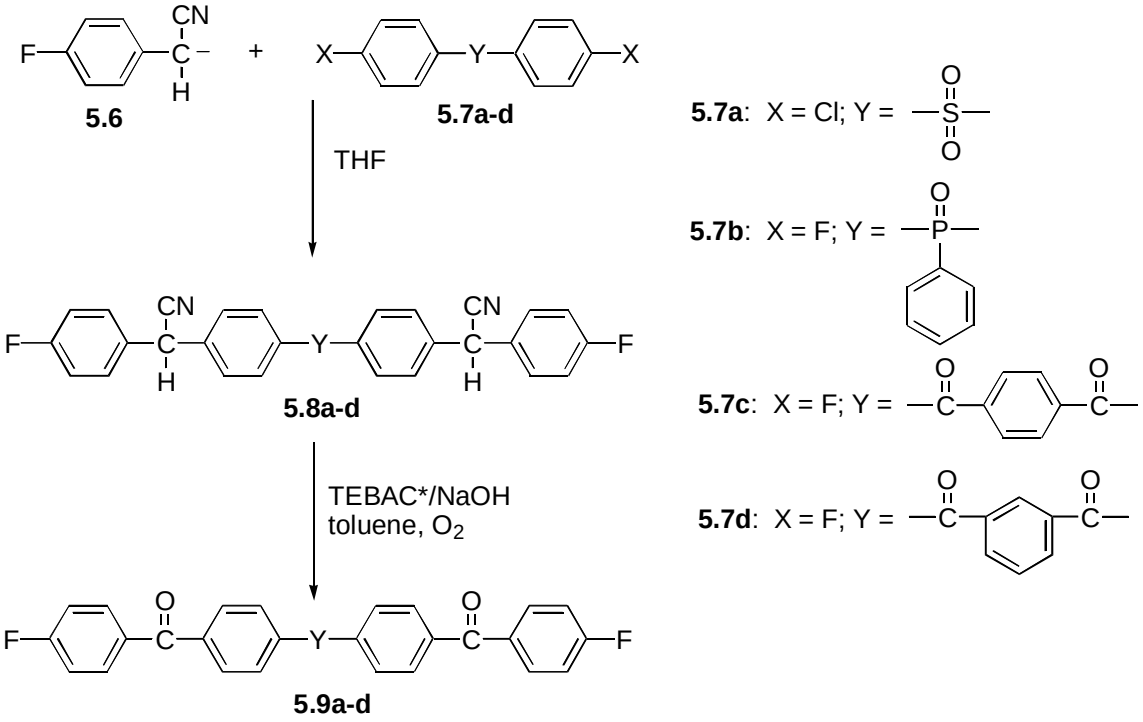
5.4a

Wolfe and coworkers[6,7] developed an efficient synthesis for activated aryl dihalides and diphenols utilizing nucleophilic aromatic substitution reactions of acyl anion equivalent **5.6** with activated dihalides **5.7a-d** to produce nitrile compounds **5.8a-d**, which undergo facile oxidative decyanation to afford monomers **5.9a-d** (Scheme 5.4). The diflouoro monomers

[6] Carver, D. R.; Greenwood, T. D.; Hubbard, J. S.; Komin, A. P.; Sachdeva, Y. P.; Wolfe, J. F. *J. Org. Chem.* **1983**, 48, 1180.
[7] Wolfe, J. F.; Campbell, J. A.; Gibson, H. W.; Greenwood, T. D.; Nguyen, P.; Yang, J. In the 4th Pacific Polymer Conference in Hawaii, December, **1995.**

were synthesized by the condensation of excess α–lithio-4-fluorophenylacetonitrile, prepared from the nitrile and *n*-BuLi, with the appropriate activated aryl dihalides in THF to give intermediate bisnitriles **5.8a-d**, followed by phase transfer catalyzed oxidative decyanation in toluene using triethylbenzylammonium chloride (TEBAC) as catalyst. The overall yields of this two step reaction were > 80% for all difluoro monomers. Similarly, a diphenol monomer was prepared from α–lithio-4-methoxy-phenylacetonitrile and 4,4'-dichlorophenyl sulfone, followed by oxidative decyanation and then ether cleavage reaction in HBr and HOAc.

Scheme 5.4



As discussed in Chapter 2, α-aminonitriles have been used as acyl anion equivalents.[8] This synthetic strategy can be utilized for the synthesis of activated dihalide monomers. This

[8] McEvoy, F. J.; Albright, J. D. *J. Org. Chem.* **1979**, 44, 4597.

chapter describes a very efficient synthesis for activated aryl dihalide monomers and diphenol monomers using α–aminonitrile chemistry.

5.2 Results and Discussion

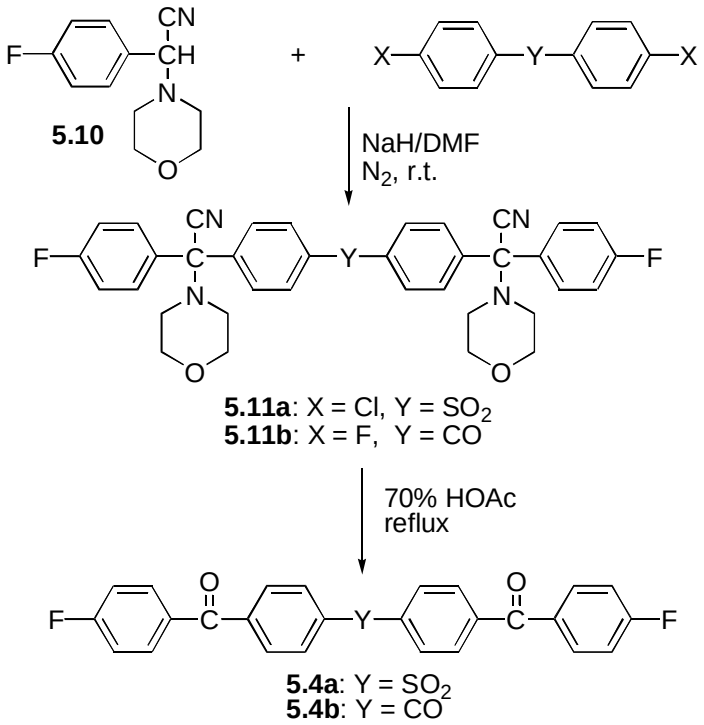
5.2.1 Synthesis of Activated Dihalide Monomers

A. Difluorotriketone and Difluorodiketone Sulfone Monomers

The non-activated halide compound, *p*-fluoroaminonitrile (**5.10**), was synthesized from *p*-fluorobenzaldehyde in 93% yield. Attempts to polymerize this AB type monomer in DMF using NaH as base failed and only starting material **5.10** was recovered. This aminonitrile can thus be utilized to synthesize activated aryl dihalide monomers for synthesis of PAEKs. Condensation of two equivalents of **5.10** with bis(*p*-chlorophenyl) sulfone in DMF with sodium hydride yielded novel difluoroaminonitrile sulfone **5.11a** in quantitative yield (Scheme 5.5, X = Cl, Y = SO_2). After the reaction was completed, indicated by the loss of the dark brown color of the carbanion, the reaction mixture was then precipitated into distilled water. The ^{1}H NMR spectrum (Figure 5.1) of the crude product shows no signal of either starting material, which indicates complete conversion. It also shows two signals in the aliphatic region corresponding to the morpholino groups and four signals in the aromatic region. The COSY spectrum in the aromatic region shows two pairs of doublets coupled to each other at 7.81 and 7.89 ppm, and a doublet of doublet at 7.03 ppm coupled with a multiplet at 7.58 ppm due to the fluorine nuclei participated in the coupling. The ^{13}C NMR spectrum (Figure 5.2) of **5.11a** shows three signals in the aliphatic region corresponding to the aminonitrile

groups. The IR spectrum (Figure 5.3) reveals sulfone absorbance at 1326, 1163 cm^{-1}, nitrile stretch at 2228 cm^{-1}, and strong C-O-C band at 1116 cm^{-1}.

Scheme 5.5



This aminonitrile **5.11a** was then hydrolyzed in 70% acetic acid to produce an activated difluorodiketone sulfone monomer **5.4a** in quantitative yield. The IR spectrum (Figure 5.4) of **4.4a** shows a strong carbonyl absorbance at 1660 cm^{-1} and the disappearance of the C-O-C peak at about 1116 cm^{-1} and aliphatic C-H stretches from 2800-3000 cm^{-1}, which is the evidence of complete hydrolysis. The ^{1}H NMR spectrum (Figure 5.1) of the crude hydrolysis product shows no signal in the aliphatic region corresponding to the mopholino groups, which indicates the complete hydrolysis of aminonitrile groups to ketone groups. The ^{13}C NMR spectrum (Figure 5.2) of **5.4a** shows no signal in the aliphatic region which also indicates the complete hydrolysis. Compound **5.4a** has a melting point of 183-184

°C, which is about 5 °C higher than a previously reported value (177-178 °C)[5]. It is soluble in many common organic solvents, such as $CHCl_3$, THF, DMF, etc. Compound **5.4a** was polymerized with bis(α–aminonitrile) **4.1a** in DMF using NaH as base, followed by acid hydrolysis to yield novel poly(ketone sulfone) **4.7a**.

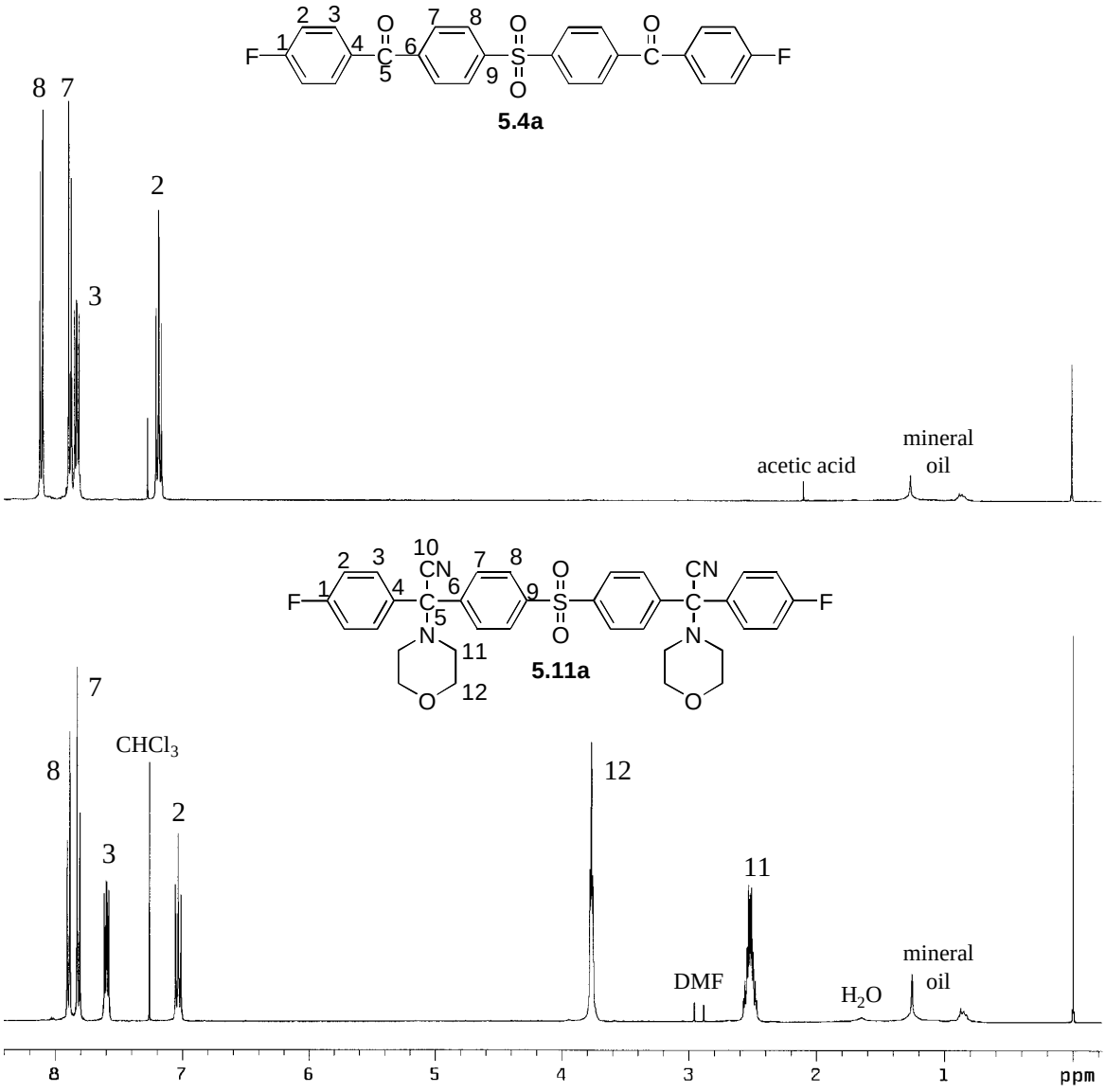


Figure 5.1 400 MHz ^{1}H NMR spectra of **5.11a** and **5.4a** in $CDCl_3$ (crude product).

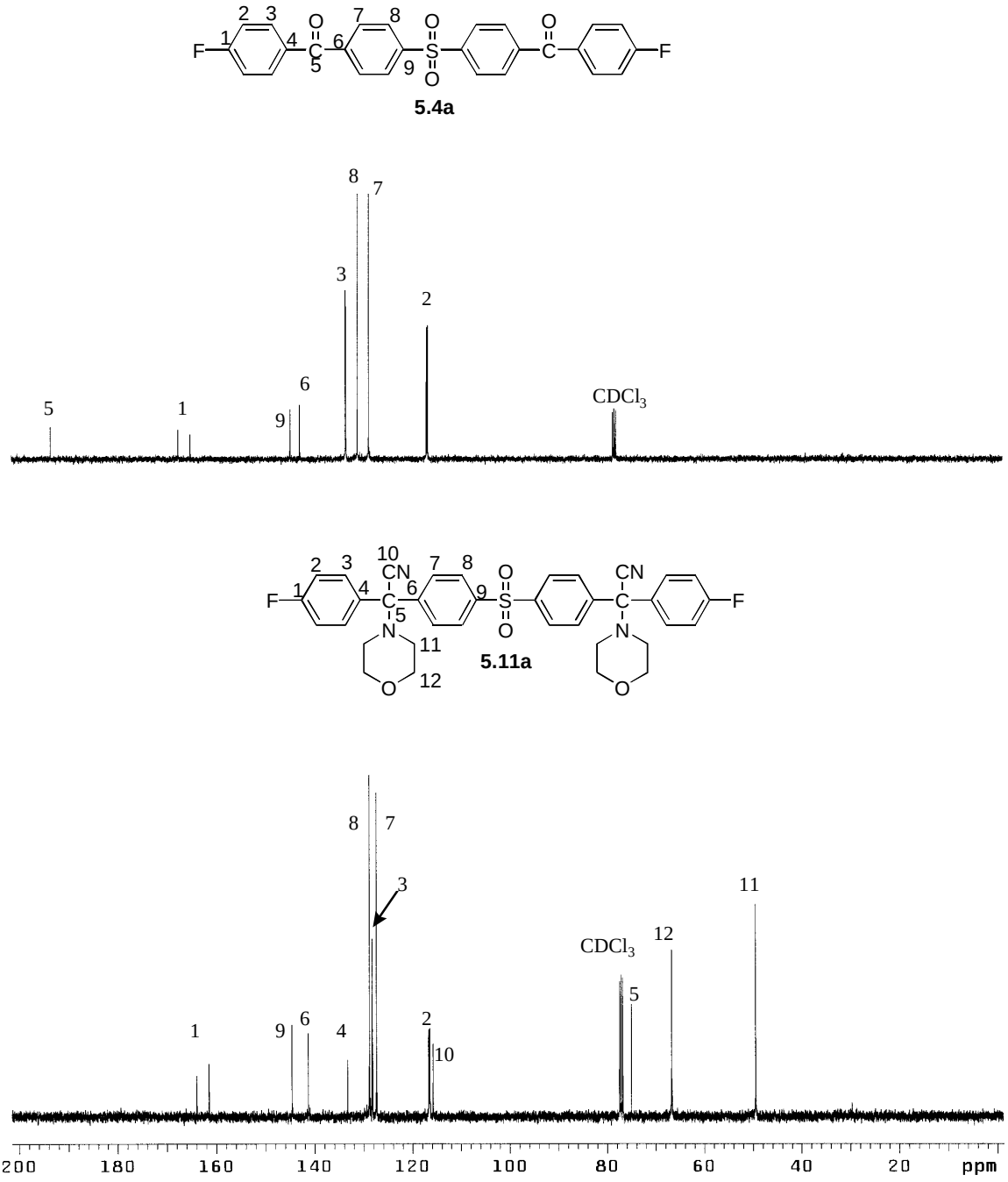
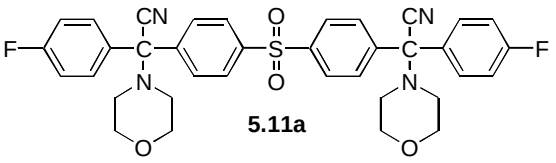


Figure 5.2 100 MHz ^{13}C NMR spectra of **5.11a** and **5.4a** in $CDCl_3$ (crude product).



5.11a

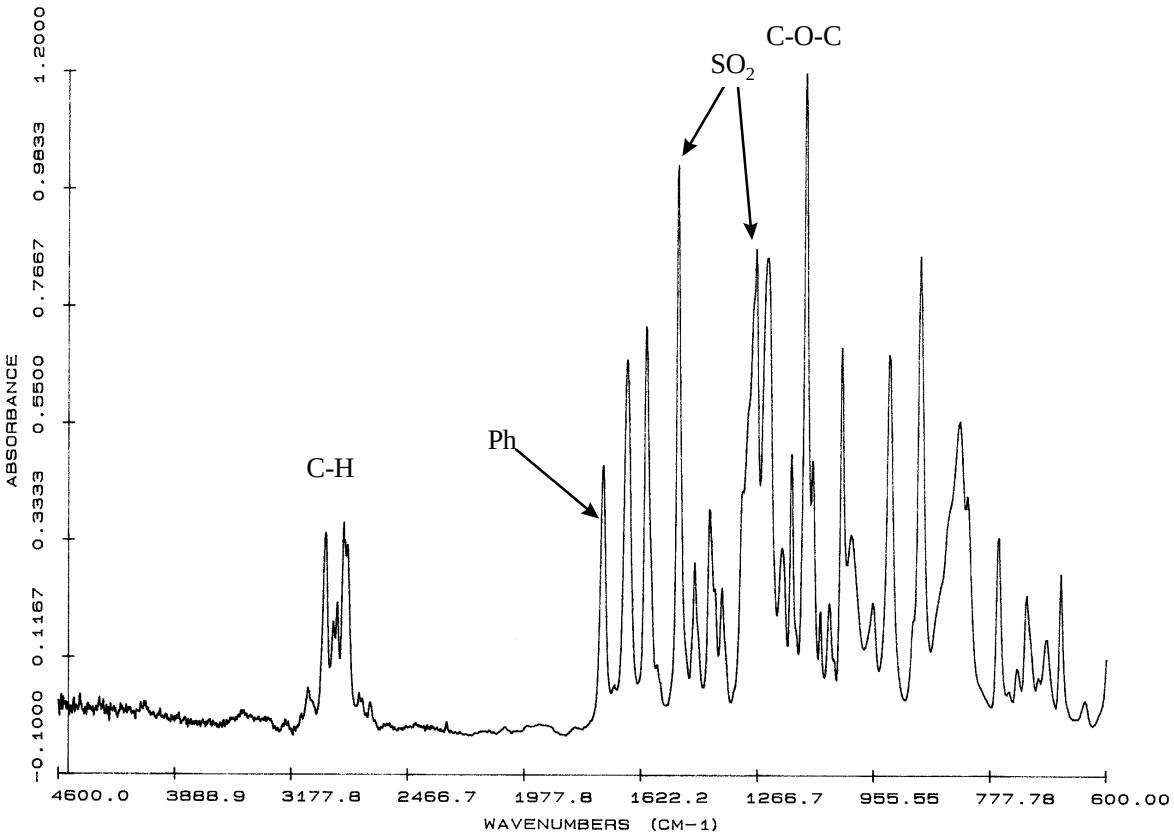
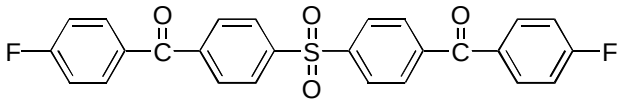


Figure 5.3 FTIR spectrum of **5.11a** (KBr).



5.4a

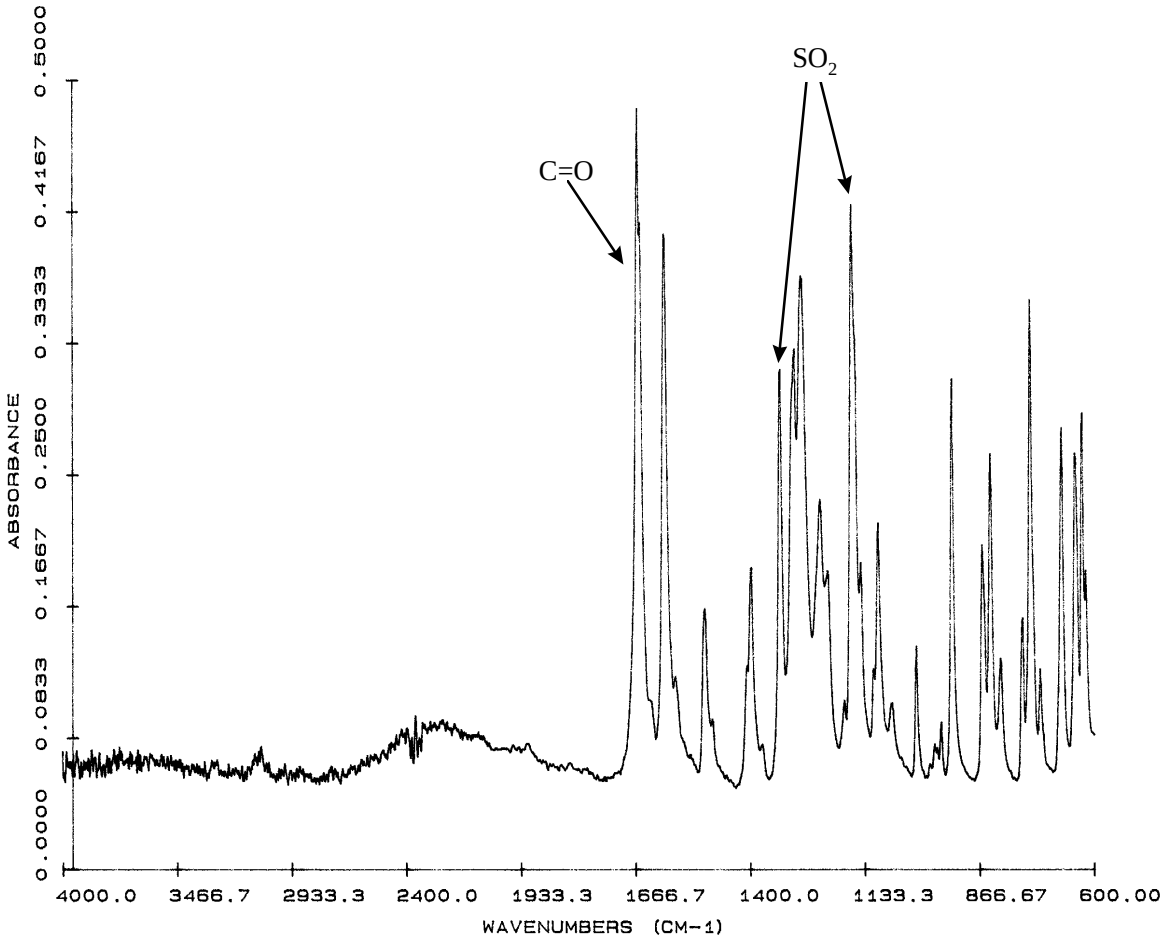


Figure 5.4 FTIR spectrum of **5.4a** (KBr).

Compound **5.11b** was obtained from 4-fluorobenzylaminonitrile (**5.10**) and 4,4'-difluorobenzophenone in quantitative yield. The stereoisomeric mixture of aminonitriles had a melting point of 98-139 °C. The ^{1}H NMR spectrum (Figure 5.5) agrees well with the structure. The IR spectrum (Figure 5.6) of **5.11b** shows a nitrile stretch at 2226 cm^{-1}, strong

carbonyl stretch at 1661 cm^{-1}, and C-O-C absorbance at 1116 cm^{-1}. Hydrolysis of **5.11b** yielded difluorotriketone monomer **5.4b** in quantitative yield. The ^{13}C NMR spectrum is consistent with the structure. Compound **5.4b** has a melting point of 293-295 °C, which is 10 °C higher than a reported value.[5] One possible reason for this is that monomers synthesized by Freidel-Crafts acylation may have *ortho* acylation products, which are difficult to separate from *para* acylation products. The monomers synthesized by this α–aminonitrile chemistry are very pure and do not need complicated purification procedures. In contrast to **5.4a**, compound **5.4b** is insoluble in most common organic solvents, such as $CHCl_3$, DMSO, acetone, etc., at room temperature. It is soluble in hot polar solvents such as NMP, DMF and DMAc. The overall yields of this two step reaction for compounds **5.4a** and **5.4b** are essentially 100%. For polymers synthesized by step growth polymerization, one of the critical requirements to obtain high molecular weight is the purity of monomers. The major advantage of this aminonitrile approach is that monomers synthesized by this aminonitrile chemistry are very pure and do not need complicated purification procedures. The activated dihalides synthesized by Friedel-Crafts acylation reaction may contain small amounts of *otho* products, which are usually difficult to separate from the desire *para* products. The overall crude yields for compounds **5.4a** and **5.4b** synthesized by Friedel-Crafts acylation were only 55-75%.[5] And these crude products needed further purification by column chromatography or recrystallization several times to obtain pure monomers. Compounds **5.4a** and **5.4b** are good precursors for synthesis of rigid arylene marcrocycles.[9,10]

[9] Xie, D. Ph.D. Thesis, VPI&SU, **1997**.
[10] Chen, M. Ph.D. Thesis, VPI&SU, **1997**.

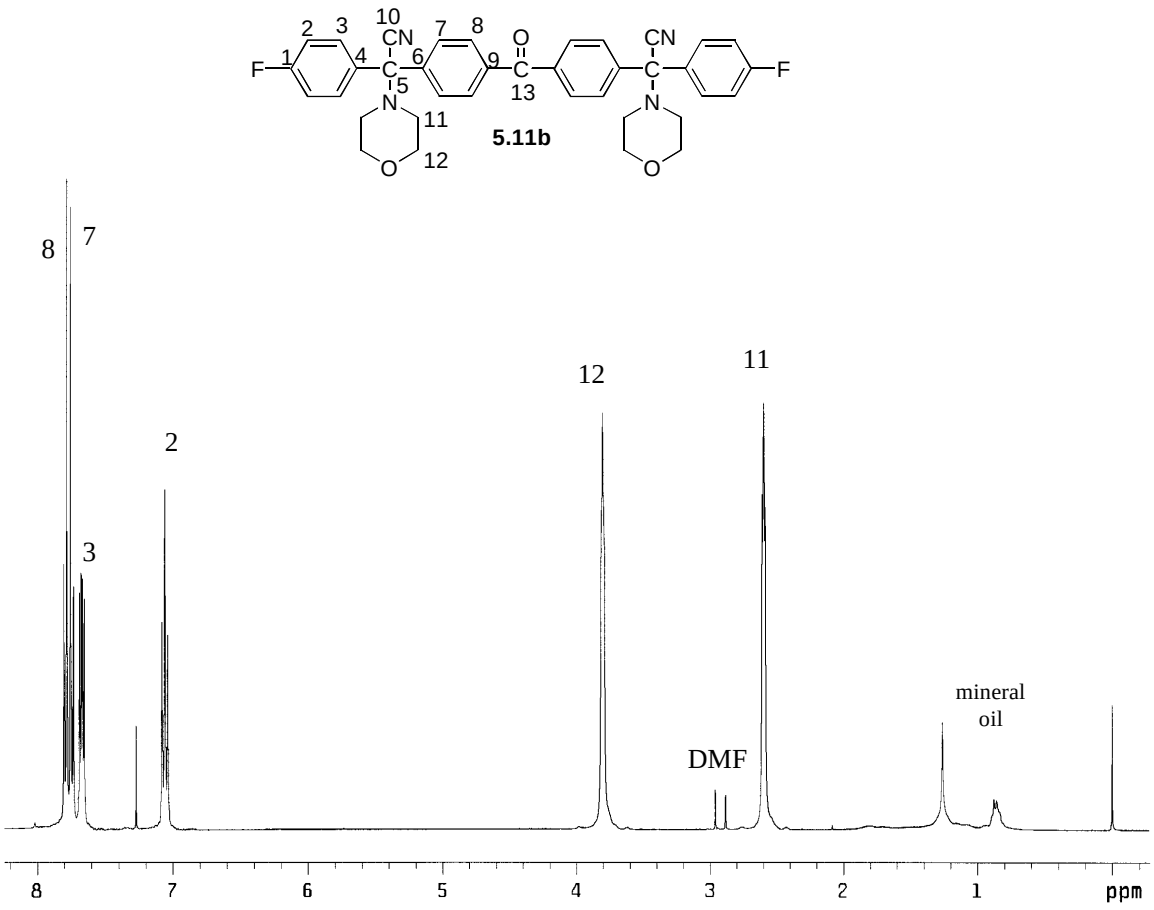


Figure 5.5 400 MHz ^{1}H NMR spectrum of **5.11b** in $CDCl_3$ (crude product).

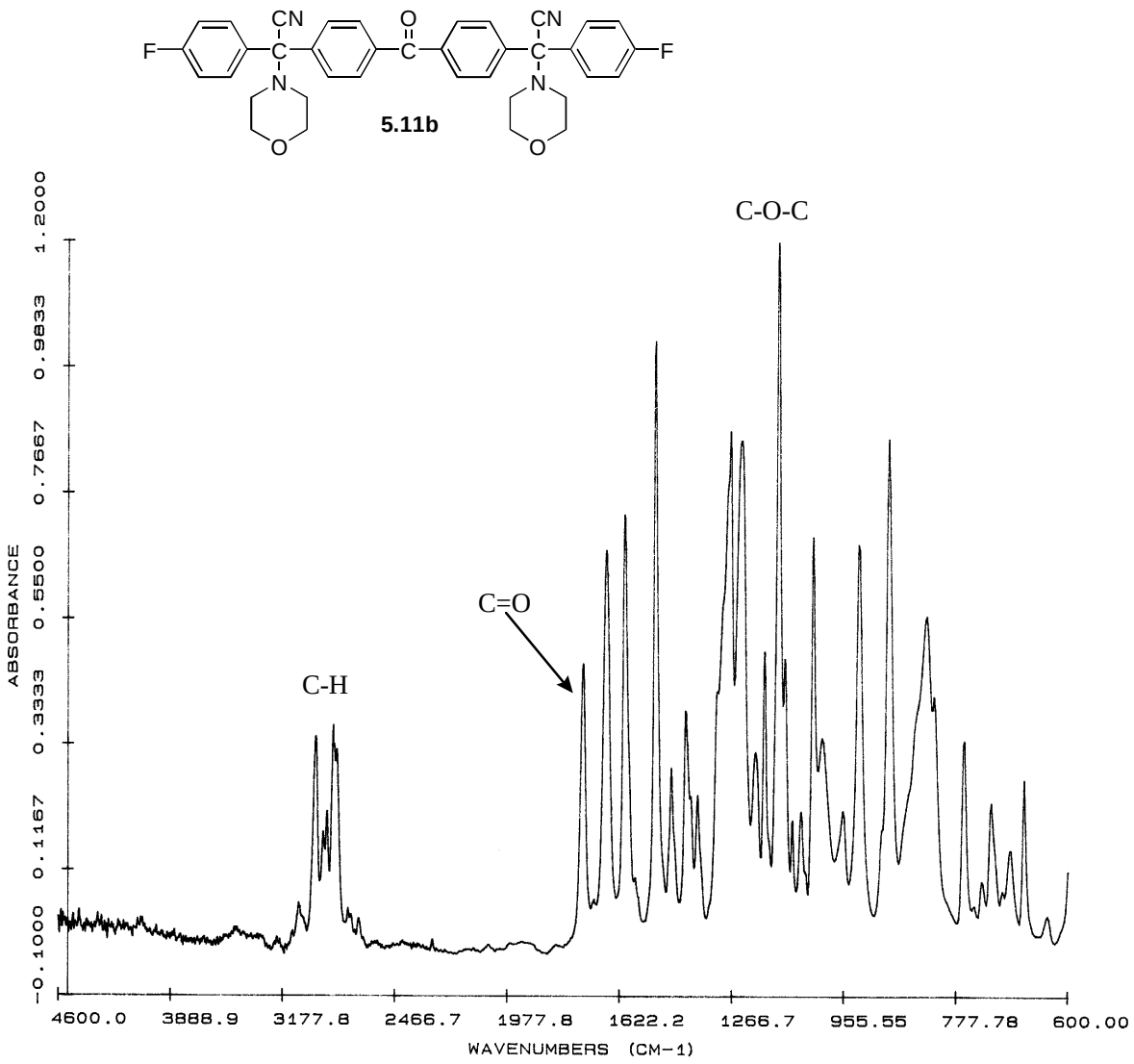


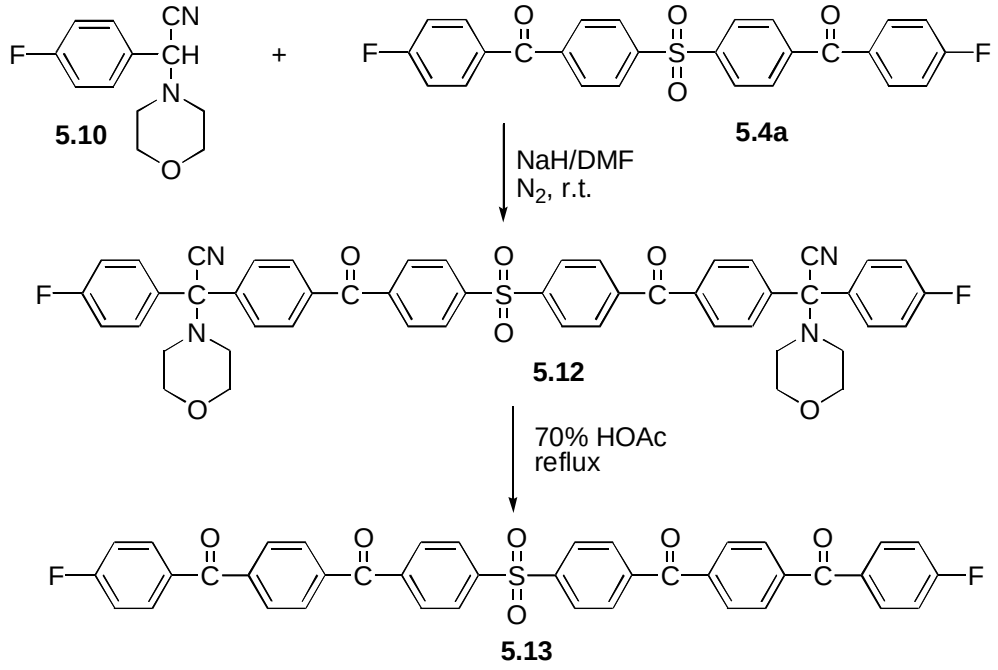
Figure 5.6 FTIR spectrum of **5.11b** (KBr).

B. Synthesis of Difluorotetraketone Sulfone Monomer (5.13)

Difluorodiketone sulfone (**5.4a**) was synthesized from aminonitrile (**5.10**) and bis(4-chlorophenyl) sulfone. Further extension of this activated dihalide was done using the same chemistry. Condensation of two equivalents of **5.10** with **5.4a** in DMF using NaH as base gave aminonitrile intermediate **5.12** in 99% yield (Scheme 5.6). The ^{1}H NMR spectrum

(Figure 5.7) in $CDCl_3$ showed two signals in the aliphatic region due to the methylene protons of the mopholino groups. Peaks in the aromatic region agree well with the structure of **5.12**. Hydrolysis of **5.12** in 70% acetic acid yielded the corresponding activated dihalide **5.13** in 96% yield. The ^{1}H NMR spectrum (Figure 5.8) of **5.13** in DMSO showed no signal in the aliphatic region which indicated that hydrolysis was complete. The assignment of the aromatic protons was done according to the COSY spectrum (Figure 5.9). **5.13** was slightly soluble in the moderately polar solvents such as DMSO and DMAc. It was recrystallized twice from DMAc. This activated dihalide monomer can be polymerized with bisaminonitriles or bisphonols to give the corresponding poly(ketone sulfone)s.

Scheme 5.6



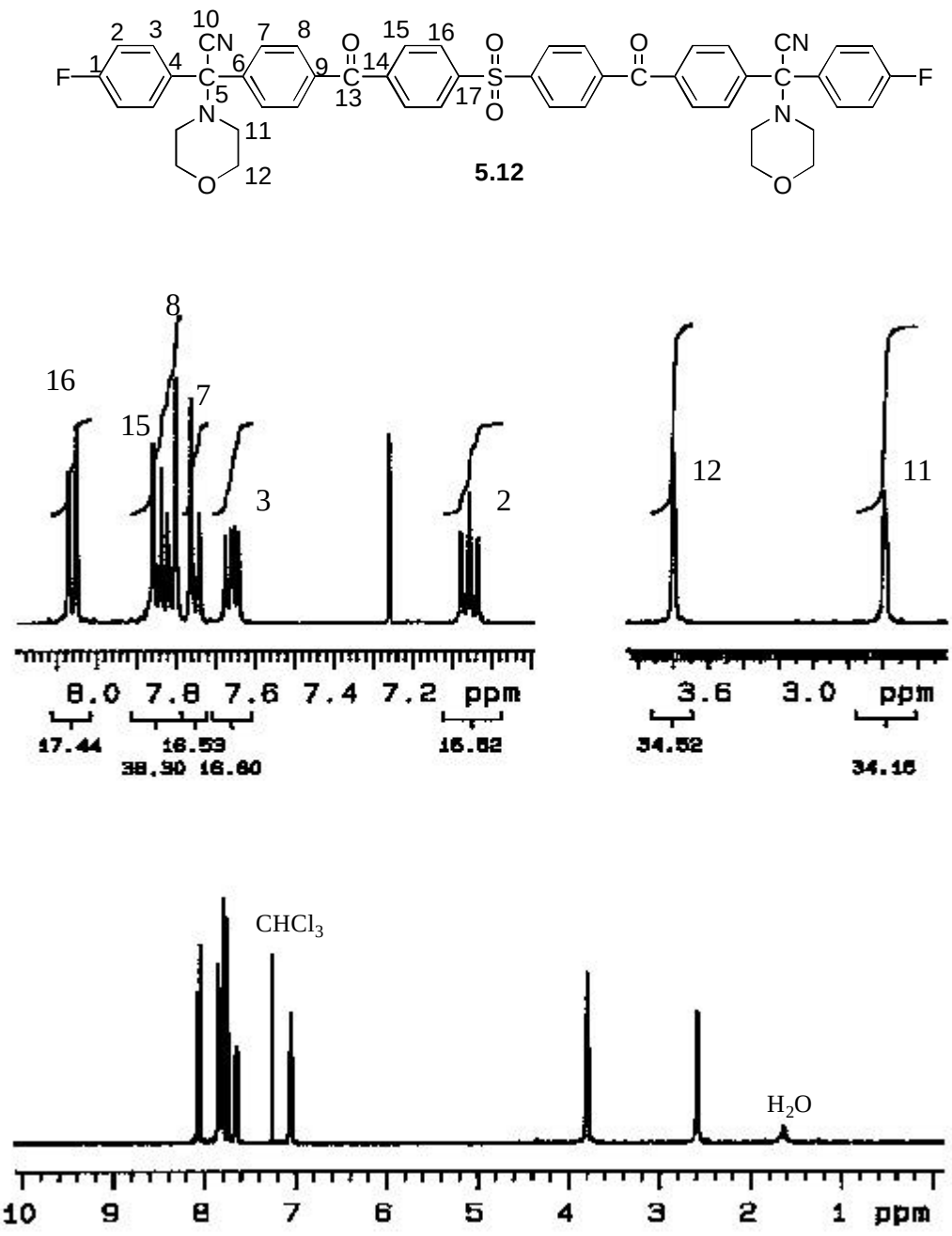
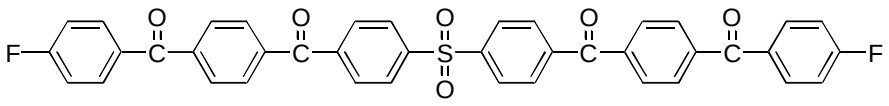


Figure 5.7 400 MHz ^{1}H NMR spectrum of **5.12** in $CDCl_3$ (crude product).



5.13

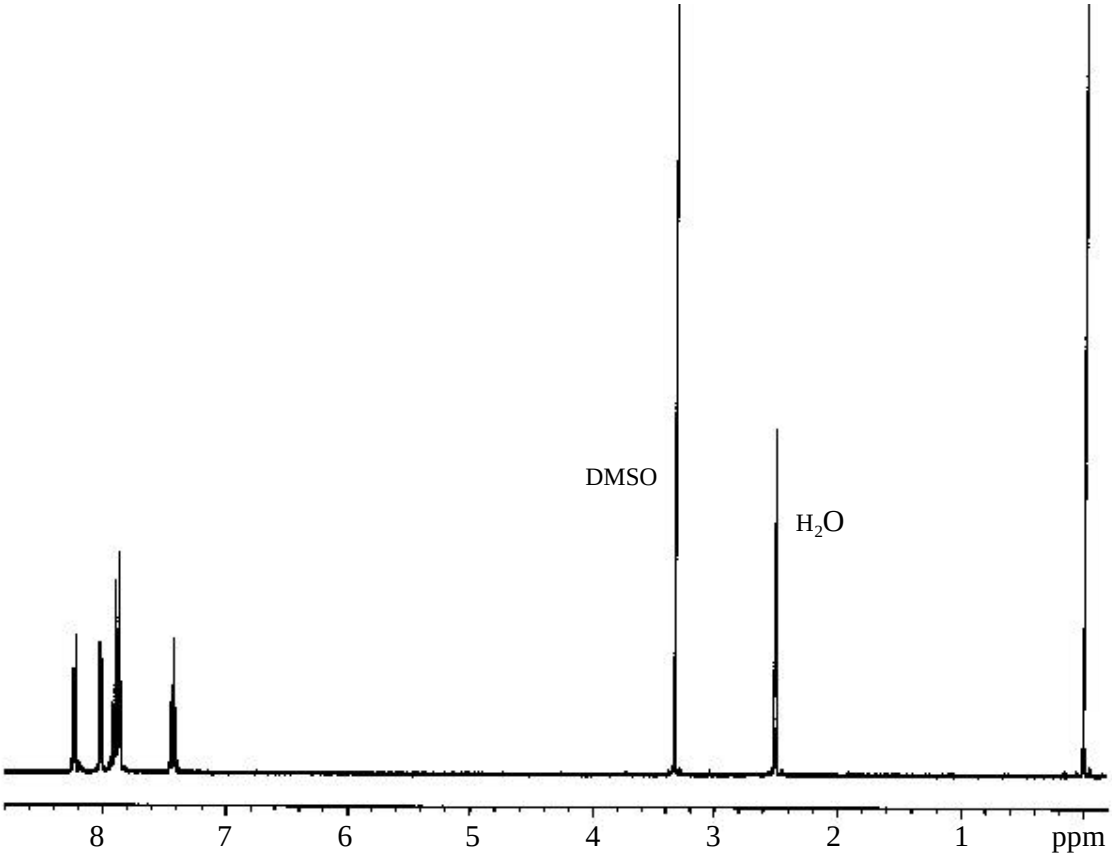
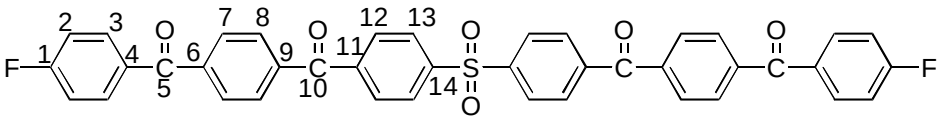


Figure 5.8 400 MHz ^{1}H NMR spectrum of **5.13** in DMSO-d_6 (crude product).



5.13

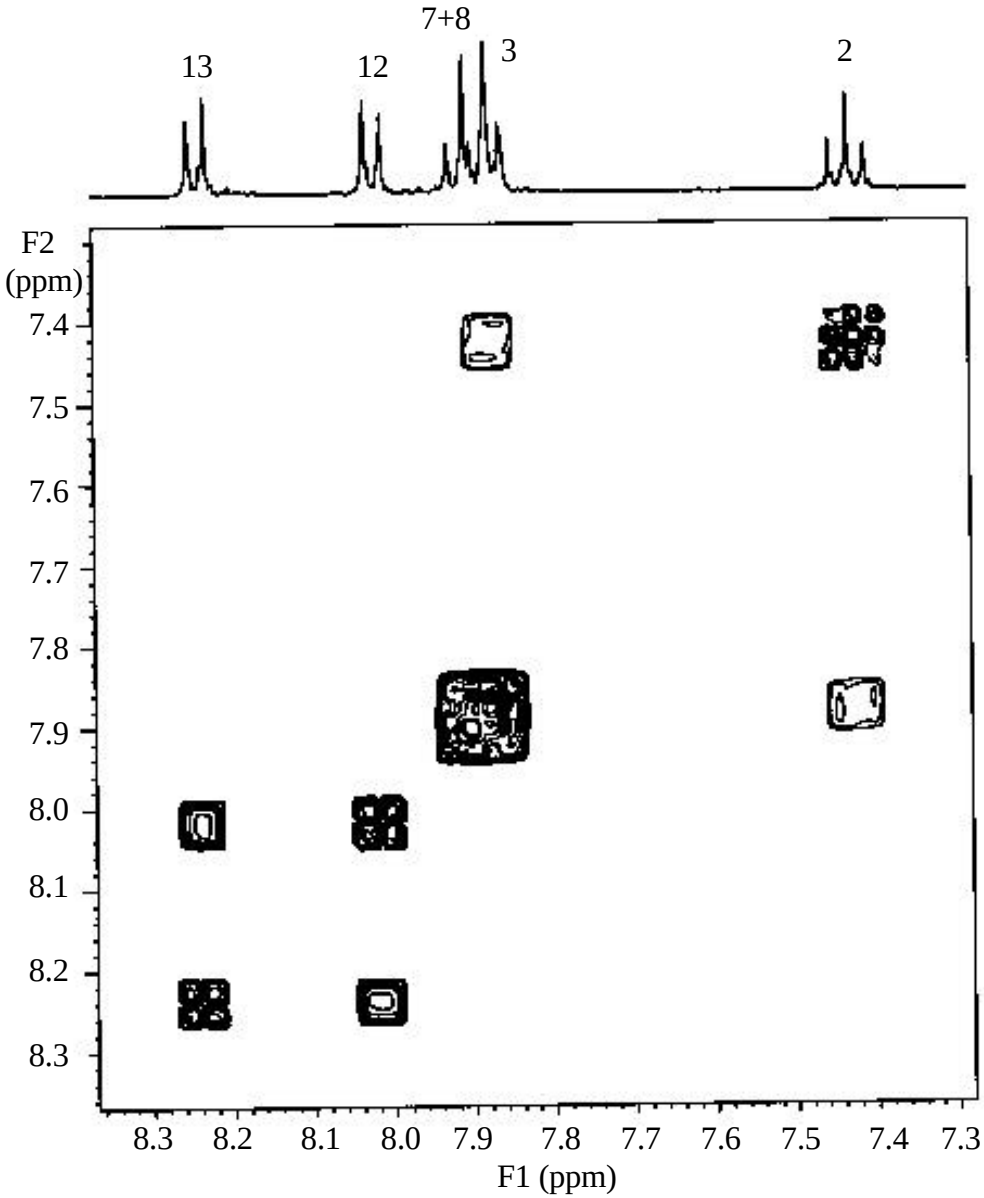
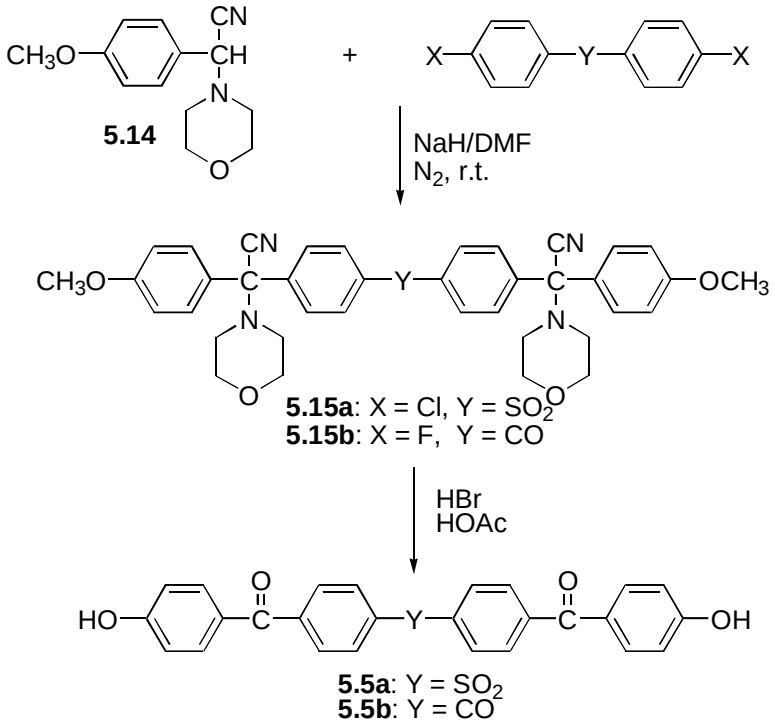


Figure 5.9 400 MHz 2D-COSY spectrum of **5.13** in DMSO-d_6.

5.2.2. Synthesis of Aryl Diketophenol Monomers

p-Methoxyaminonitrile (**5.14**) was synthesized from 4-anisaldehyde in 97% yield. The IR and ^{1}H NMR spectra agree well with the structure of **5.14**. Condensation of two equivalents of **5.14** with bis(4-chlorophenyl) sulfone in DMF using NaH as base gave protected keto phenol compound **5.15a** in 100% yield (Scheme 5.7).

Scheme 5.7



The IR spectrum of **5.15a** shows C-H stretch at 3000-2800 cm^{-1}, nitrile stretch at 2226 cm^{-1}, aromatic ring breathing at 1606 cm^{-1}, sulfone absorbance at 1326, 1160 cm^{-1} and C-O-C stretch at 1116 cm^{-1}. The ^{1}H NMR spectrum shows a sharp singlet for the methyl protons at 3.75 ppm together with multiplets for the methylene protons of the morpholino groups. The stereoisomeric ratio is about 1:1 according to the integrals of methylene protons. In the aromatic region there are two pairs of doublets coupled to each other, integrating for

four protons each. Hydrolysis and cleavage of the ether group in HBr and acetic acid yielded ketophenol monomer **5.5a** in 96% yield. The structure was confirmed by FTIR and NMR spectra.

Compound **5.15b** was synthesized from aminonitrile **5.14** and 4,4'-difluorobenzophenone in 99% yield. The IR and NMR spectra agree with the structure shown. Hydrolysis and ether cleavage in HBr and acetic acid afforded diphenol monomer **5.5b** in 97% yield. The NMR and IR spectra are consistent with the structure of the compound. Diphenol monomers **5.5a** and **5.5b** can be synthesized from the corresponding difluoro monomers **5.4a** and **5.4b** in 60-70% yields by hydrolysis in an aqueous solution of NaOH and DMSO.[5]

Similarly, a series of new monomers can be prepared using this aminonitrile chemistry, including keto phenols and their sulfone analogs. These keto monomers can be used to synthesize poly(ether ketone)s or their copolymers. These new keto compounds can be used as precursors for synthesis of rigid arylene macrocycles with low viscosity, which can be polymerized by ring opening to produce high performance polymers.

5.3 Conclusions

A very efficient synthesis for activated dihalide monomers containing keto groups was developed based on α–aminonitrile chemistry. The aminonitrile intermediates and activated dihalide monomers were obtained in quantitative yields. Further chain extension was also demonstrated. This method is suitable for any activated dihalide by reaction with 2 equivalents of 4-fluorobenzylaminonitrile (**5.10**) and NaH, followed by hydrolysis to produce

a new monomer with two more *p*-fluorobenzoyl units. Similarly, diphenol monomers can also be synthesized in high yield using 4-methoxybenzylaminonitrile (**5.14**).

5.4 Experimental

Materials and Instrumentation

Sodium hydride (60% dispersion in light mineral oil) and anhydrous DMF were purchased from Aldrich and used as received. Melting points were determined using a Haake-Buchler apparatus and are corrected. The proton NMR spectra were obtained on a Varian Unity 400 spectrometer operating at 399.95 MHz and reported in δ units. Tetramethylsilane was used as the internal standard. All ^{1}H COSY (COrrelated SpectroscopY) spectra were obtained using a 16-step phase cycle. The spectral window was centered. A 90° pulse (177.5 μs) was used for both dimensions (F_1 and F_2); 128 increments of 512 point FID's (acquisition time 247 ms) with 16 scans were accumulated. Zerofilling, multiplication by sine window function, Fourier transformation and symmetrization were applied. The ^{13}C NMR spectra were obtained on a Varian Unity 400 spectrometer operating at 100.60 MHz. Spectra were proton-decoupled and recorded in deuteriochloroform (76.9) as solvent and internal standard. FTIR spectra were recorded on a Nicolet MX-1 with KBr pellets.

α-(*N*-Morpholino)-*p*-fluorobenzyl Cyanide (5.10)

$NaHSO_3$ (15.61 g, 150 mmol) was dissolved in 250 mL of water and 15.84 mL (150 mmol) of 4-fluorobenzaldehyde was added to the flask and the mixture was stirred for 2 h until homogenous. Morpholine (13.07 mL, 150 mmol) was added all at once and the stirring

was continued for 2 hours. Then 7.35 g (150 mmol) of NaCN was added to the solution and the solution was stirred for 6 hours, at the end of which, a shiny white solid had precipitated out. The stirring was continued for another 10 hours. The solid was filtered and dried to yield 30.63 g (93%) of **7**, mp 61.7-63.2 °C (lit.[11] 60-63 °C). It was recystallized from 19:1/hexanes:EtOAc to give shiny white needles, mp 62.8-63.8 °C. FTIR (KBr) 2862, 2826 (C-H stretch), 2226 (CN), 1606, 1508 (phenyl), 1456 (methylene scissor), 1116 (C-O-C), cm^{-1}. ^1H NMR ($CDCl_3$) δ 2.57-2.59 (m, 4 H), 3.71-3.77 (m, 4 H), 4.79 (s, 1 H), 7.09-7.13 (m, 2 H), 7.50-7.54 (m, 2 H).

4,4'-Bis(4-fluoro-α-cyano-α-*N*-morpholinobenzyl) Diphenyl Sulfone (5.11a)

Compound **5.10** (4.41 g, 20 mmol) was dissolved in 30 mL of dry DMF along with 2.87 g (10 mmol) of bis(*p*-chlorophenyl) sulfone in a flame dried round bottom flask under N_2. NaH (0.88 g, 22 mmol, 60% in mineral oil) was added all at once and immediately the vigorous bubbling of H_2 and a color change to greenish and then brown were observed. The stirring was continued for 3 days until the color of the solution faded to light yellow. The solution was then quenched into ice cold water; a white precipitate was collected and dried to yield 6.55 g (100%) of **5.11a**, mp 231 °C (dec.). The crude product was extracted with MeOH and dried. FTIR (KBr) 2963, 2894 (C-H stretch), 2228 (CN), 1601, 1506 (phenyl), 1456 (methylene scissor), 1326, 1163 (sulfone), 1116 (C-O-C), cm^{-1}. ^1H NMR ($CDCl_3$) δ 2.46-2.55 (m, 8 H), 3.75-3.77 (m, 8 H), 7.03 (m, 4 H), 7.56-7.61 (m, 4 H), 7.81(d, *J* = 8.8 Hz, 4 H), 7.89 (d, *J* = 8.8 Hz, 4 H). ^{13}C NMR ($CDCl_3$) δ 163.94, 161.45 (C-1), 144.59 (C-

[11] Albright, J. D.; McEvoy, F. J.; Moran, D. B. *J. Heterocyclic Chem.* **1979**, 15, 881.

9), 141.28 (C-6), 133.29, 133.25 (C-4), 128.80 (C-8), 128.26, 128.17 (C-3), 127.35 (C-7), 116.62, 116.40 (C-2), 115.75 (C-10), 75.01 (C-5), 66.71 (C-12), and 49.41 (C-11).

4,4'-Bis(4-fluorobenzoyl)diphenyl Sulfone (5.4a)

Compound **5.11a** (2.00 g, 4.32 mmol) was suspended in 25 mL of 70% AcOH and the mixture was refluxed. Within about 10 min., the solid had dissolved and in about 10 more min., white precipitation was observed. The mixture was quenched into 200 mL of cold water and the solid was filtered, washed with water and dried, 1.41 g (100%). It was recrystallized from benzene to give white needles, mp 183-184 °C (lit.[5]: 177-178 °C). FTIR (KBr) 1660, 1656 (C=O), 1598, 1506 (phenyl), 1330, 1163 (sulfone), cm^{-1}. ^{1}H NMR ($CDCl_3$) δ 7.18 (t, *J* = 8.6 Hz, 4 H), 7.82 (m, 4 H), 7.88 (d, *J* = 8.4 Hz, 4 H), 8.10 (d, *J* = 8.4 Hz, 4 H). ^{13}C NMR ($CDCl_3$) δ 193.28 (C-5), 167.16, 164.62 (C-1), 144.15 (C-9), 142.17 (C-6), 132.74, 132.64 (C-3), 130.27 (C-8), 127.94 (C-7), and 115.93, 115.71 (C-2).

4,4'- Bis(4-fluoro-α-cyano-α-*N*-morpholinobenzyl)benzophenone (5.11b)

Procedural details are the same as for the synthesis of compound **5.11a**. Compound **5.10** (4.40 g, 20 mmol), 4,4'-difluorobenzophenone (2.18 g, 10 mmol) and NaH (0.88 g, 22 mmol, 60% in mineral oil) were stirred in 30 mL of dry DMF at room temperature for 3 days. The yield was 5.68 g (100%), mp 98-139 °C (diastereomers). FTIR (KBr) 2967, 2854 (C-H stretch), 2226 (CN), 1661 (benzophenone), 1603,1506 (phenyl), 1116 (C-O-C), cm^{-1}. ^{1}H NMR ($CDCl_3$) δ 2.57-2.61 (m, 8 H), 3.78-3.82 (m, 8 H), 7.06 (t, *J* = 8.4 Hz, 4 H), 7.64 -7.68 (m, 4 H), 7.73 (d *J* = 8.6 Hz, 4 H), 7.78 (d, *J* = 8.6 Hz, 4 H). ^{13}C NMR ($CDCl_3$) δ 194.55

(C=O), 163.86, 161.38 (CF), 143.35 (C), 137.24 (C), 133.87, 133.83 (C), 130.80 (CH), 128.26, 128.18 (CH), 126.32 (CH), 116.45, 116.23 (CH), 116.05 (CN), 75.16 (C), 66.80 (CH_2), and 49.43 (CH_2).

4,4'-Bis(4-fluorobenzoyl)benzophenone (5.4b)

A procedure analogous to synthesis of **5.4a** from **5.11a** was used to obtain **5.4b** from **5.11b** in 100% crude yield. Recrystallization from DMF afforded white crystals, mp 293-295 °C (lit.[5]: 282-283 °C). FTIR (KBr) 1646 (C=O), 1592, 1504 (phenyl), cm^{-1}. It is insoluble in most common organic solvents at room temperature.

4,4'-Bis[(*p*-fluoro-α-cyano-α-*N*-morpholinobenzyl)benzoyl] Diphenyl Sulfone (5.12)

Compound **5.4b** (2.31 g, 5.00 mmol) was dissolved in 30 mL of anhydrous DMF along with compound **5.10** (2.20 g, 10.0 mmol) in a flamed dried round bottom flask under N_2. NaH (0.44 g, 11.0 mmol, 60% in mineral oil) was added to the flask all at once and immediately the vigorous bubbling of H_2 and a color change to greenish and then brown were observed. The stirring was continued for 2 days until the color of the solution faded to light yellow. The solution was then quenched into 10 fold excess of water; a white precipitate was collected and dried to yield 4.08 g (99%) of **5.12**, mp 162- 200 °C (diastereomers). The crude product was washed with MeOH and dried. ^{1}H NMR ($CDCl_3$) δ 2.59 (m, CH_2, 4 H), 3.79 (m, CH_2, 4 H), 7.06 (m, 2 H), 7.65 (m, 2 H), 7.75 (d, *J* = 8.4 Hz, 2 H), 7.81 (d, *J* = 8.4 Hz, 2 H), 7.85 (d, *J* = 8.4 Hz, 2 H), 8.06 (d, *J* = 8.4 Hz, 2 H). ^{13}C NMR ($CDCl_3$) δ 163.94, 161.45 (C), 144.59 (C), 141.28 (C), 133.29, 133.25 (C), 128.80 (CH), 128.26 (CH), 128.17

(CH), 127.35 (CH), 116.62, 116.40 (CH), 115.75 (CN), 75.01 (C), 66.71 (CH_2), and 49.41 (CH_2).

4,4'-Bis[(*p*-fluorobenzoyl)benzoyl] Diphenyl Sulfone (5.13)

In a 100 mL of round bottom flask, 2.00.g of compound **5.12** was suspended in 30 mL of 70% AcOH. The mixture was heated to reflux for 2 h. The mixture was then quenched into 500 mL of H_2O. The light yellow powder was filtered and washed with water and methanol. The sample weighed 1.56 g (96%), mp: 281.2-282.8. Compound **5.13** is slightly soluble in moderately polarity solvents such as DMAC, DMF, DMSO, etc. ^{1}H NMR (DMSO-d_6) δ 7.42 (m, 2 H), 7.85-7.92 (m, 6 H), 8.02 (d, *J* = 8.4 Hz, 2 H), 8.24 (d, *J* = 8.4 Hz, 2 H). ^{13}C NMR ($CDCl_3$) δ 194.55 (C=O), 163.86, 161.38 (CF), 143.35 (C), 137.24 (C), 133.87, 133.83 (C), 130.80 (CH), 128.26, 128.18 (CH), 126.32 (CH), 116.45, 116.23 (CH), 116.05 (CN), 75.16 (C), 66.80 (CH_2), and 49.43 (CH_2).

α-(*N*-Morpholino)-*p*-methoxybenzyl cyanide (5.14)

To a stirred solution of $NaHSO_3$ (10.41 g, 100 mmol) in water (300 mL) was added 4-methoxybenzaldehyde (13.62 g 100 mmol), and the heterogeneous mixture was allowed to stir for 2 hours until homogenous. Morpholine (8.71 mL, 100 mmol) was then added to the solution all at once. The mixture was allowed to stir for 2 hours until homogenous, at the end of which NaCN (4.90 g, 100 mmol) was added to the solution. The stirring was continued for 10 hours and the mixture was put in a refrigerator for 5 hours. The pale yellow precipitate was suction filtered and dried to give **5.14**, 24.12 g (97%), mp: 76.1-78.5 °C. It was

recrystallized from hexanes to give white shiny needles, mp 78.4-79.8 °C (lit.[8] mp: 77-79 °C). FTIR (KBr) 2970,2933, 2823 (C-H stretch), 1616 (phenyl), 1118 (C-O-C), cm^{-1}. ^1H NMR ($CDCl_3$) δ 2.55-2.58 (m, 4 H), 3.69-3.73 (m, 4 H), 4.75 (s, 1 H), 6.92 (d, *J* = 8.6 Hz, 2 H), 7.43 (d, *J* = 8.6 Hz, 2 H).

4,4'-Bis(*p*-methyloxy-α-cyano-α-*N*-morpholinobenzyl) Diphenyl Sulfone (5.15a)

Procedural details are the same as the synthesis of compound **5.11a**. Compound **5.14** (4.97 g, 20 mmol), bis(4-chlorophenyl) sulfone (2.87 g, 10 mmol) and NaH (0.88 g, 22 mmol, 60% in mineral oil) were stirred in 30 mL of dry DMF under N_2 at room temperature for 3 days. Yield was 6.76 g (100%), mp 98-139 °C. FTIR (KBr) 2962, 2853 (C-H stretch), 2226 (CN), 1606, 1510 (phenyl), 1326, 1160 (sulfone), 1116 (C-O-C), cm^{-1}. ^1H NMR ($CDCl_3$) δ 2.36-2.50 (m, 4 H), 2.52-2.70 (m, 4 H), 3.75-3.77 (m, 14 H), 6.83 (d, *J* = 9.0 Hz, 4 H), 7.49 (d, *J* = 9.0 Hz, 4 H), 7.81 (d, *J* = 8.6 Hz, 4 H), 7.87 (d, *J* = 8.6 Hz, 4 H). ^{13}C NMR ($CDCl_3$) δ 159.94 (C), 145.14 (C), 141.04 (C), 129.24 (C), 128.68 (CH), 127.60 (CH), 127.27 (CH), 116.05 (CN), 114.67 (CH), 75.27 (C), 66.79 (CH_2), 55.37, 55.34 (CH_3) and 49.36 (CH_2).

4,4'-Bis(4-hydroxybenzoyl)diphenyl Sulfone (5.5a)

The dimethoxy ether **5.15a** (3.39 g, 5.00 mmol) was dissolved in 36 mL of HBr (0.200 mol, 45 w/v% in acetic acid) and 10 mL of distilled water. The mixture was heated at reflux for 14 hours. Upon heating, the mixture became reddish brown. The mixture was then quenched into 500 mL of distilled water. A light pink solid was filtered and dried under vacuum at 100 °C for 36 hours, 2.27 g (99%). It was recrystallized from 40% aqueous acetic

acid solution, 2.20 g (96%); mp: 229.1-230.8 °C (lit.[5]: 224-225 °C). ^{1}H NMR (DMSO-d_6) δ 6.89 (d, *J* = 8.6 Hz, 2 H), 7.65 (d, *J* = 8.6 Hz, 2 H), 7.87 (d, *J* = 8.6 Hz, 2 H), 8.18 (d, *J* = 8.6 Hz, 2 H), 10.09 (s, 2 H). ^{13}C NMR ($CDCl_3$) δ 195.43 (C=O), 161.37 (C), 153.29 (C), 141.34 (C), 129.46 (CH), 128.87 (C), 127.12 (CH), 125.05 (CH) and 116.75 (CN). FTIR (KBr) 1659 (C=O), 1600 (phenyl), 1334, 1161 (sulfone), cm^{-1}.

4,4'-Bis(4-hydroxybenzoyl)benzophenone (5.5b)

Procedural details are the same as the hydrolysis of compound **5.5a**. Compound **5.15b** (3.21 g, 5.00 mmol) and 36 mL of HBr in acetic acid were used. The yield was 2.14 g (97%); mp: 252.3-253.5 °C (lit.[5]: 248-249 °C). ^{1}H NMR (DMSO-d_6) δ 6.91 (d, *J* = 8.7 Hz, 2 H), 7.85 (d, *J* = 8.7 Hz, 2 H), 7.91 (d, *J* = 8.6 Hz, 2 H), 8.18 (d, *J* = 8.6 Hz, 2 H), 10.03 (s, 2 H). ^{13}C NMR ($CDCl_3$) δ 195.43 (C=O), 161.37 (C), 153.29 (C), 141.34 (C), 129.46 (CH), 128.87 (C), 127.12 (CH), 125.05 (CH) and 116.75 (CN). FTIR (KBr) 3235 (OH, broad), 1649 (C=O) and 1598 (phenyl), cm^{-1}.