Appendix B

ISOTOPIC LABELLING FOR SANS AND NMR

B.1 Appendix

All reagents were purchased and used as received from Aldrich, unless otherwise noted.

B.1.1 Synthesis of Perdeuterated 4-Pentyl-4′-Cyanobiphenyl (d_{19}5CB)

Using the same method employed by Michael Kempe[1, 2], a platinum-catalyzed deuterium exchange is used to perdeuterate 4-pentylbiphenyl (5B) (Scheme B.1).[3] 5B (20 mL, purchased from TCI America and used as received) is combined with deuterium oxide (D_2O, 20 mL), platinum black (400 mg), and a piece of aluminum foil (approximately 2 cm^2) in a high-pressure, Teflon-lined reaction vessel. The vessel is mounted on a rotating arm inside an oven, where it is continually agitated and held at a temperature between 170 and 200 °C. Approximately once every seven days, the vessel is removed from the oven and, after cooling to room temperature, it is opened and the water inside is replaced with fresh D_2O. At this time, a small sample of 5B is taken and the deuterium content is measured by NMR spectroscopy: a proton NMR spectrum is collected from a solution containing known quantities of 5B (~ 100 mg) and DCM (~ 1 mg) in deuterated chloroform ($CDCl_3$) and the DCM peak is used as a standard to calculate the degree of deuteration.

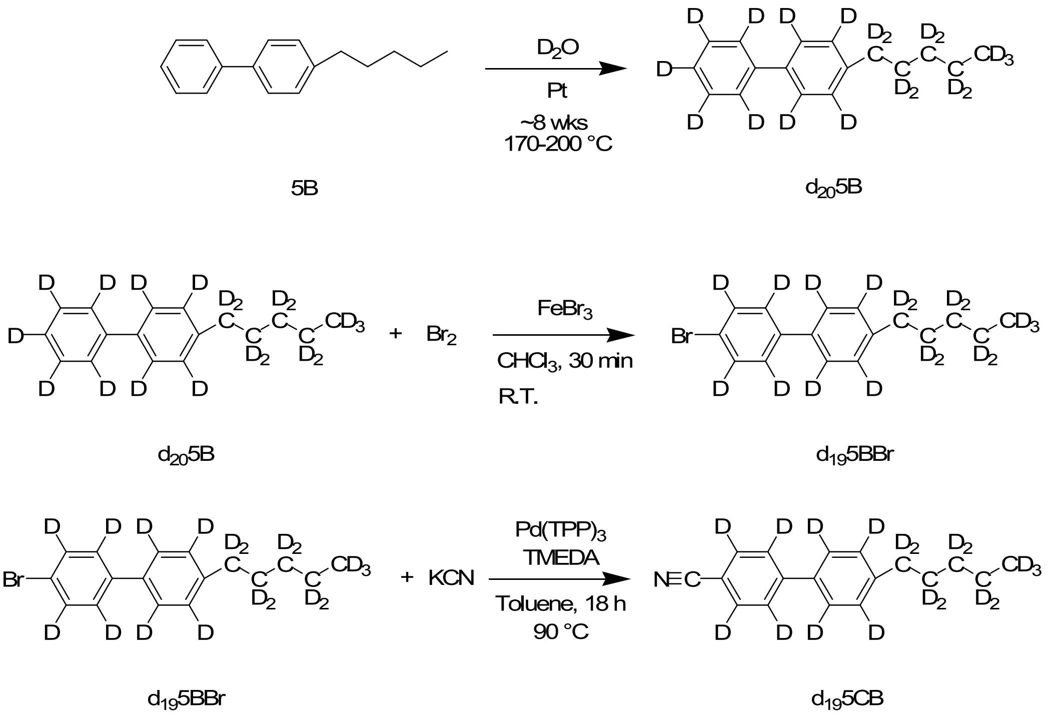
The process is repeated for approximately eight weeks until a high degree of deuterium substitution is achieved, typically 95 mol %.

After completing the deuterium substitution, perdeuterated 5B (d_{20}5B) is converted to perdeuterated 4-pentyl-4-cyanobiphenyl (d_{19}5CB) in two steps (Scheme B.1). First, d_{20}5B (26 g, 110 mmol) is reacted with one equivalent of elemental bromine (5.4 mL, 110 mmol) catalyzed by $FeBr_3$ (900 mg, 3.0 mmol). The d_{20}5B and $FeBr_3$ are dissolved together in 50 mL chloroform then Br_2 is added dropwise at room temperature. The mixture is allowed to stir at room temperature for 30 minutes after completing the Br_2 addition. The product, perdeuterated 4-pentyl-4-bromobiphenyl (d_{19}5BBr), is precipitated with water, filtered, and dried. The dry product is recrystallized from hot hexane (200 mL heated to 40 °C), achieving 31% yield overall (11 g, 34 mmol). Next, d_{19}5BBr is reacted with potassium cyanide to yield the final product, d_{19}5CB. A palladium catalyst ($Pd(TPP)_2$) is synthesized by dissolving palladium II acetate ($Pd(OAc)_2$, 180 mg, 0.80 mmol) together with triphenyl phosphine (TPP, 420 mg, 1.6 mmol) in 40 mL anhydrous toluene and heated at 50 °C until the mixture turns bright red. The remaining reagents are then added directly to the catalyst solution: d_{19}5BBr (1.8 g, 5.5 mmol), KCN (360 mg, 5.5 mmol), and the phase-transfer catalyst *N*, *N*, *N*′, *N*′-tetramethylethylenediamine (TMEDA, 160 μL, 1.1 mmol), which promotes the solubility of KCN in organic solvent.[4] The reaction flask is purged with inert gas, then sealed and heated at 90 °C for approximately 18 hours. The product is purified on a silica gel column using 1% ethyl acetate in hexane as the mobile phase, and the typical yield is approximately 75%. The d_{19}5CB is often repeatedly fractionated on a silica gel column and fractions having very low nematic-isotropic transition temperatures (T_{NI}) are discarded. The T_{NI} of the final product, obtained by combining d_{19}5CB from several separate syntheses, is usually between 32.0 and 33.5 °C, slightly below that of hydrogenous 5CB ($T_{NI} = 35$ °C). The deuterium content of d_{19}5CB is measured by proton NMR in the same way as for d_{20}5B (Figure B.1).

B.1.2 Synthesis of Deuterium-Labeled 4-Cyano-4′-hydroxybiphenyl (d_2CHB)

Deuterium atoms are incorporated into 4-cyano-4′-hydroxybiphenyl (CHB) by acid-catalyzed deuterium exchange.[3] A solution of deuterium bromide (DBr) and deuterium phosphate (D_3PO_4) is synthesized by dropwise addition of phosphorus tribromide (2.1g, 7.8 mmol) to D_2O (3.4g, 170 mmol) at 0 °C. Excess PBr_3 is removed from the DBr / D_3PO_4 solution by extraction with ether. The DBr / D_3PO_4 solution is added to a solution of CHB (1.9g, 9.7 mmol, purchased from TCI America and used as received) in 13 g perdeuterated acetone. The mixture is refluxed for approximately 72 hours, during which time a dark brown tar forms in the reaction flask. The product is selectively dissolved in ether and the tar separated by filtration. The ether solution is extracted repeatedly with water until the aqueous layer ceases to become yellow during washing. The ether layer is then dried with anhydrous Na_2SO_4 and the product is applied to approximately 100 mL of silica gel by evaporating the ether. The product-loaded silica gel is eluted with hexane, followed by 5% ethyl acetate in hexane, followed by 50% ethyl acetate in hexane. The waxy, orange product is purified on another silica gel column using 50% ethyl acetate in hexane as the mobile phase then recrystallized from toluene heated to 100 °C. The overall yield is approximately 20%, and the deuterium content is measured by proton NMR (Figure B.2). Deuterium-labeled CHB is attached to a polymer according to the methods described in Appendix A.

B.2 Schemes



Scheme B.1 Synthesis of perdeuterated 4-pentyl-4′-cyanobiphenyl (d_{19}5CB). The hydrogen atoms of 4-pentylbiphenyl (5B) are exchanged for deuterium via platinum-catalyzed exchange with D_2O to make perdeuterated 4-pentylbiphenyl (d_{20}5B). This is then reacted with elemental bromine to make 4-pentyl-4′-bromobiphenyl (d_{19}5BBr), which is subsequently reacted with potassium cyanide to yield the product. Typically, between 90 and 95 mol % of the hydrogen atoms are replaced with deuterium in the final product.

Scheme B.2 Deuterium labeling of 4-cyano-4′-hydroxybiphenyl (d_2CHB). Heating CHB in perdeuterated, acidic solution results in exchange of the hydrogens *ortho*- to the hydroxyl group.

B.3 Figures

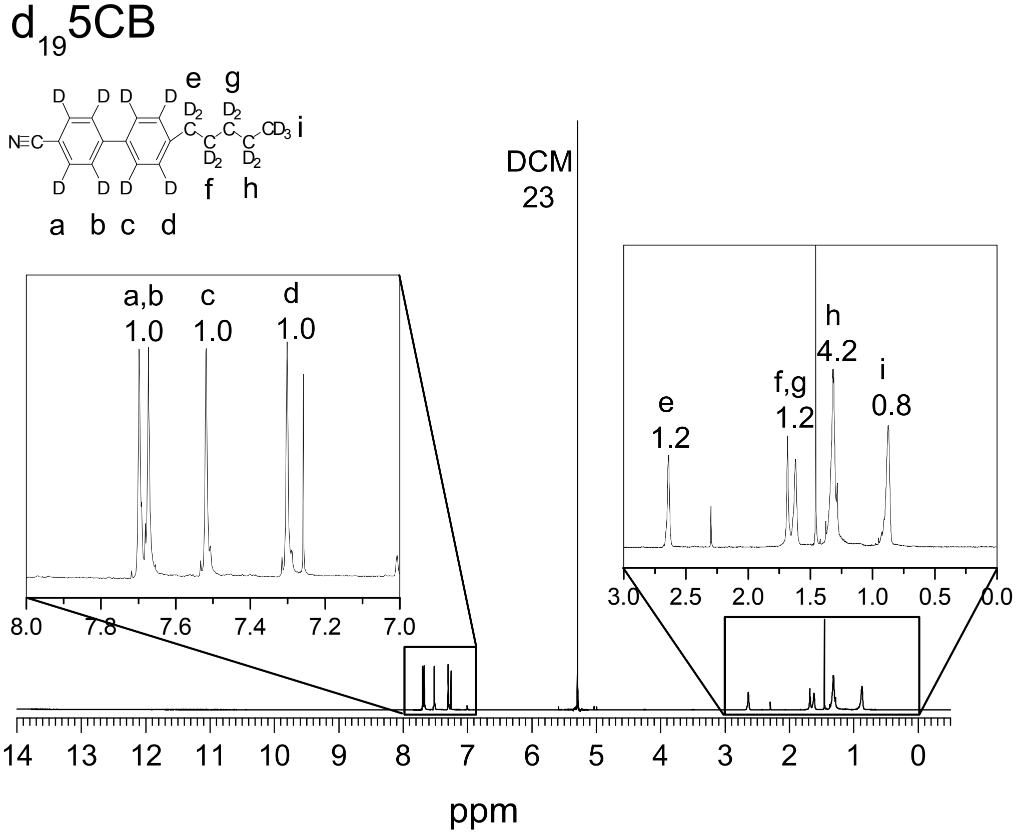


Figure B.1 300 MHz proton NMR spectrum of d_{19}5CB and dichloromethane (DCM) in $CDCl_3$ used to calculate the deuterium content. The number under each peak assignment is the relative intensity (integrated area) per mole of hydrogen at that site, taking into account the relative amounts of d_{19}5CB and DCM in the sample. The mole fraction of hydrogen at a specific site on the d_{19}5CB molecule is calculated by dividing its relative intensity by that of DCM. In this particular sample, 94 mol % of the total hydrogen atoms have been replaced with deuterium.

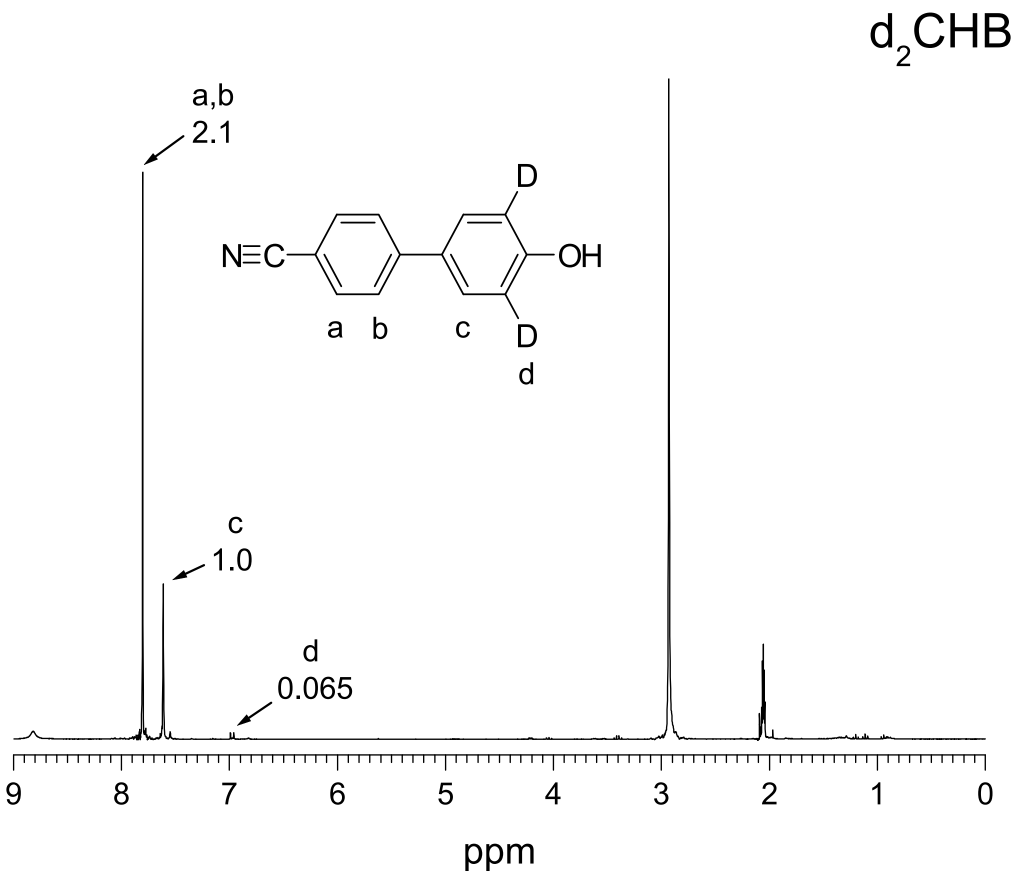


Figure B.2 300MHz proton NMR spectrum of d_2CHB in d_6-acetone. The number under each peak assignment gives the relative intensity (integrated area). The molecule's deuterium content is measured from the ratio of the peak intensity at $\delta = 7.0$ ppm to that at $\delta = 7.6$ ppm, or half that at $\delta = 7.8$ ppm. In this case, 94 mol % of the hydrogen atoms in the position *para-* to the hydroxyl group have been replaced with deuterium.

B.4 References

[1] Wu, S. T.; Wang, Q. H.; Kempe, M. D.; Kornfield, J. A. Perdeuterated cyanobiphenyl liquid crystals for infrared applications. *J. Appl. Phys.* **2002**, *92*, 7146-7148.

[2] Kempe, M. D. Rheology and dynamics of side-group liquid crystalline polymers in nematic solvents. Ph.D. Thesis, California Institute of Technology, Pasadena, CA,

[3] Thomas, A. F. *Deuterium Labeling in Organic Chemistry*, Appleton-Century-Crofts: New York, 1971.

[4] Sundermeier, M.; Zapf, A.; Beller, M. Palladium-Catalyzed Cyanation of Aryl Halides: Recent Developments and Perspectives. *Eur. J. Inorg. Chem.* **2003**, *19*, 3513-3526.