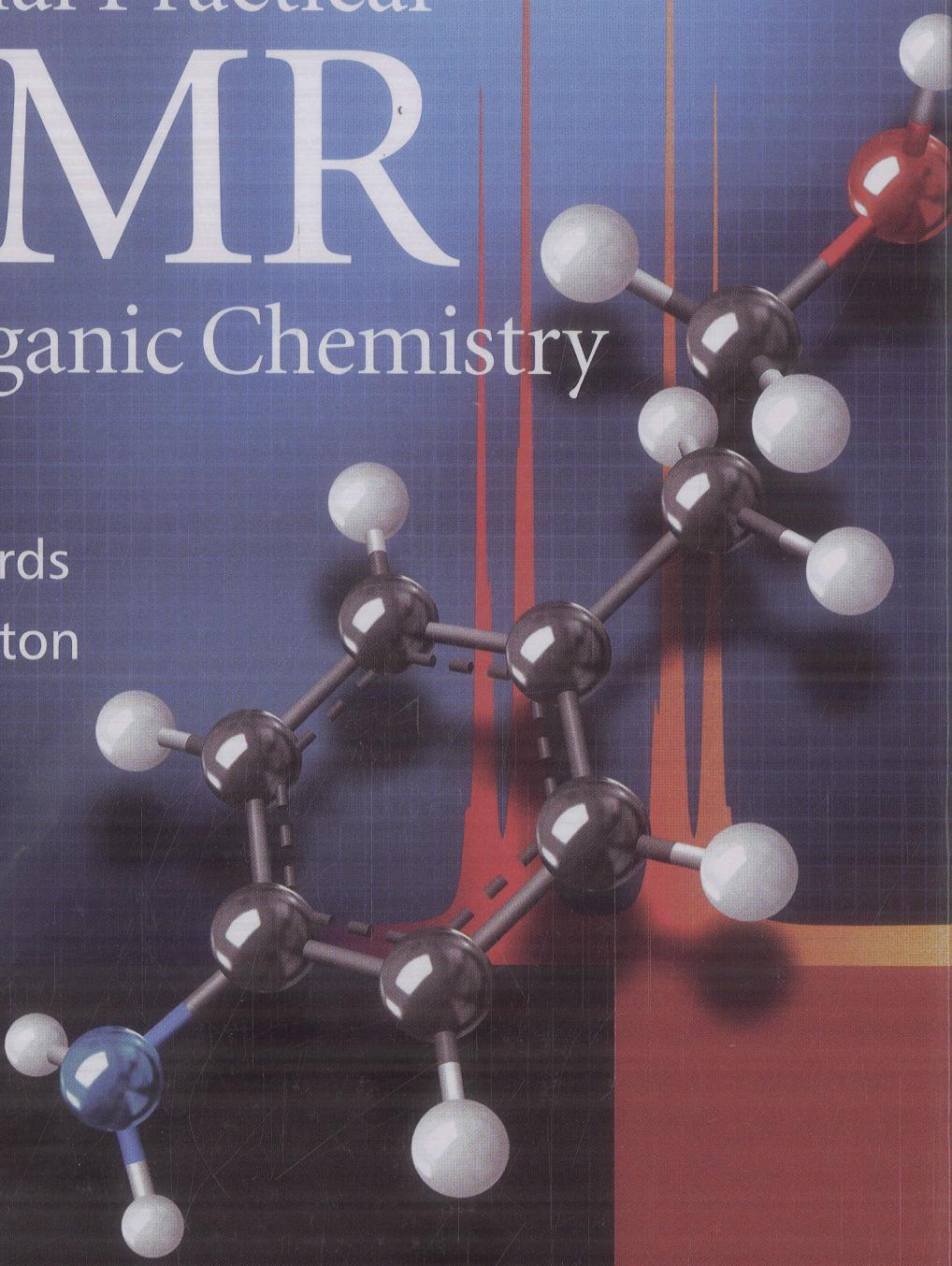


# Essential Practical NMR for Organic Chemistry

S. A. Richards  
J. C. Hollerton

 WILEY



# Contents

## Introduction

xi

<b>1 Getting Started</b>	<b>1</b>
1.1 The Technique	1
1.2 Instrumentation	2
1.3 CW Systems	2
1.4 FT Systems	3
1.4.1 Origin of the Chemical Shift	6
1.4.2 Origin of 'Splitting'	7
1.4.3 Integration	9
<b>2 Preparing the Sample</b>	<b>11</b>
2.1 How Much Sample Do I Need?	12
2.2 Solvent Selection	13
2.2.1 Deutero Chloroform ( $\text{CDCl}_3$ )	14
2.2.2 Deutero Dimethyl Sulfoxide ( $\text{D}_6\text{-DMSO}$ )	14
2.2.3 Deutero Methanol ( $\text{CD}_3\text{OD}$ )	15
2.2.4 Deutero Water ( $\text{D}_2\text{O}$ )	16
2.2.5 Deutero Benzene ( $\text{C}_6\text{D}_6$ )	16
2.2.6 Carbon Tetrachloride ( $\text{CCl}_4$ )	16
2.2.7 Trifluoroacetic Acid ( $\text{CF}_3\text{COOH}$ )	16
2.2.8 Using Mixed Solvents	17
2.3 Spectrum Referencing (Proton NMR)	17
2.4 Sample Preparation	18
2.4.1 Filtration	19
<b>3 Spectrum Acquisition</b>	<b>23</b>
3.1 Number of Transients	23
3.2 Number of Points	24
3.3 Spectral Width	25
3.4 Acquisition Time	25
3.5 Pulse Width/Pulse Angle	25
3.6 Relaxation Delay	27
3.7 Number of Increments	27
3.8 Shimming	28
3.9 Tuning and Matching	30
3.10 Frequency Lock	30

3.10.1	Run Unlocked	30
3.10.2	Internal Lock	30
3.10.3	External Lock	31
3.11	To Spin or Not to Spin?	31
<b>4</b>	<b>Processing</b>	<b>33</b>
4.1	Introduction	33
4.2	Zero Filling and Linear Prediction	33
4.3	Apodization	34
4.4	Fourier Transformation	36
4.5	Phase Correction	36
4.6	Baseline Correction	38
4.7	Integration	39
4.8	Referencing	39
4.9	Peak Picking	39
<b>5</b>	<b>Interpreting Your Spectrum</b>	<b>41</b>
5.1	Common Solvents and Impurities	44
5.2	Group 1 – Exchangeables and Aldehydes	46
5.3	Group 2 – Aromatic and Heterocyclic Protons	48
5.3.1	Monosubstituted Benzene Rings	50
5.3.2	Multisubstituted Benzene Rings	54
5.3.3	Heterocyclic Ring Systems (Unsaturated) and Polycyclic Aromatic Systems	57
5.4	Group 3 – Double and Triple Bonds	61
5.5	Group 4 – Alkyl Protons	63
<b>6</b>	<b>Delving Deeper</b>	<b>67</b>
6.1	Chiral Centres	67
6.2	Enantiotopic and Diastereotopic Protons	72
6.3	Molecular Anisotropy	74
6.4	Accidental Equivalence	76
6.5	Restricted Rotation	78
6.6	Heteronuclear Coupling	82
6.6.1	Coupling between Protons and $^{13}\text{C}$	82
6.6.2	Coupling between Protons and $^{19}\text{F}$	84
6.6.3	Coupling between Protons and $^{31}\text{P}$	87
6.6.4	Coupling between $^1\text{H}$ and other Heteroatoms	89
6.6.5	Cyclic Compounds and the Karplus Curve	91
6.6.6	Salts, Free Bases and Zwitterions	96
<b>7</b>	<b>Further Elucidation Techniques – Part 1</b>	<b>101</b>
7.1	Chemical Techniques	101
7.2	Deuteration	101
7.3	Basification and Acidification	103

7.4	Changing Solvents	104
7.5	Trifluoroacetylation	104
7.6	Lanthanide Shift Reagents	106
7.7	Chiral Resolving Agents	106
<b>8</b>	<b>Further Elucidation Techniques – Part 2</b>	<b>111</b>
8.1	Instrumental Techniques	111
8.2	Spin Decoupling (Homonuclear, 1-D)	111
8.3	Correlated Spectroscopy (2-D)	112
8.4	Total Correlation Spectroscopy (1- and 2-D)	116
8.5	The Nuclear Overhauser Effect and Associated Techniques	116
<b>9</b>	<b>Carbon-13 NMR Spectroscopy</b>	<b>127</b>
9.1	General Principles and 1-D $^{13}\text{C}$	127
9.2	2-D Proton–Carbon (Single Bond) Correlated Spectroscopy	130
9.3	2-D Proton–Carbon (Multiple Bond) Correlated Spectroscopy	133
9.4	Piecing It All Together	136
9.5	Choosing the Right Tool	137
<b>10</b>	<b>Some of the Other Tools</b>	<b>143</b>
10.1	Linking HPLC with NMR	143
10.2	Flow NMR	144
10.3	Solvent Suppression	145
10.4	Magic Angle Spinning NMR	146
10.5	Other 2-D Techniques	147
10.5.1	INADEQUATE	147
10.5.2	J-Resolved	147
10.5.3	Diffusion Ordered Spectroscopy	148
10.6	3-D Techniques	149
<b>11</b>	<b>Some of the Other Nuclei</b>	<b>151</b>
11.1	Fluorine	151
11.2	Phosphorus	152
11.3	Nitrogen	152
<b>12</b>	<b>Quantification</b>	<b>157</b>
12.1	Introduction	157
12.2	Relative Quantification	157
12.3	Absolute Quantification	158
12.3.1	Internal Standards	158
12.3.2	External Standards	158
12.3.3	Electronic Reference	159
12.3.4	QUANTAS Technique	159
12.4	Things to Watch Out For	160
12.5	Conclusion	161

<b>13 Safety</b>	<b>163</b>
13.1 Magnetic Fields	163
13.2 Cryogens	165
13.3 Sample-Related Injuries	166
<b>14 Software</b>	<b>167</b>
14.1 Acquisition Software	167
14.2 Processing Software	167
14.3 Prediction and Simulation Software	169
14.3.1 $^{13}\text{C}$ Prediction	169
14.3.2 $^1\text{H}$ Prediction	171
14.3.3 Simulation	172
14.3.4 Structural Verification Software	172
14.3.5 Structural Elucidation Software	172
<b>15 Problems</b>	<b>173</b>
15.1 Ten NMR Problems	173
15.2 Hints	194
15.3 Answers	195
<b>Glossary</b>	<b>205</b>
<b>Index</b>	<b>211</b>