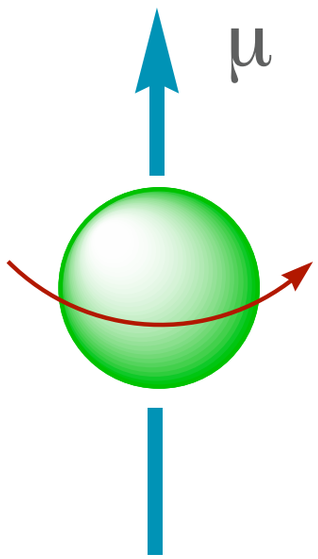
NMR Spectroscopy

NMR Phenomenon

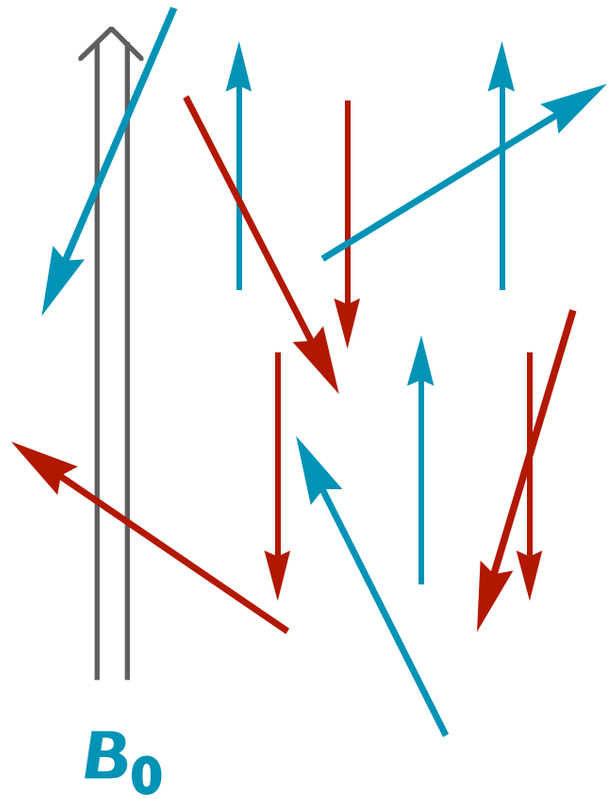
- Nuclear Magnetic Resonance



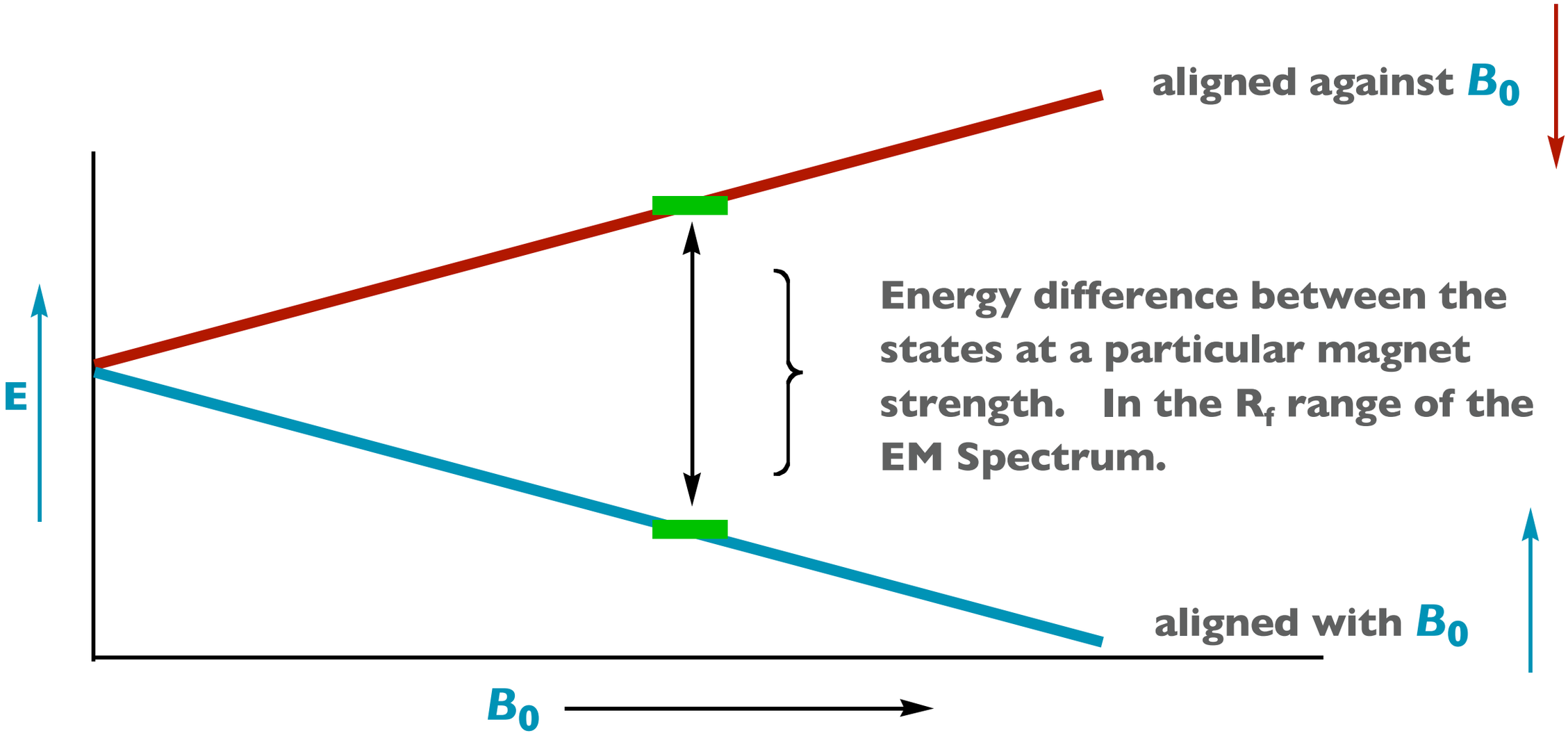
A spinning charged particle generates a magnetic field.

A nucleus with a spin angular momentum will generate a magnetic moment (μ).

If these tiny magnets are placed in an applied magnetic field (B_o), they will adopt two different states - one aligned with the field and one aligned against the field. The energy difference between these two states is what we are observing with NMR.



Nuclear Spin States



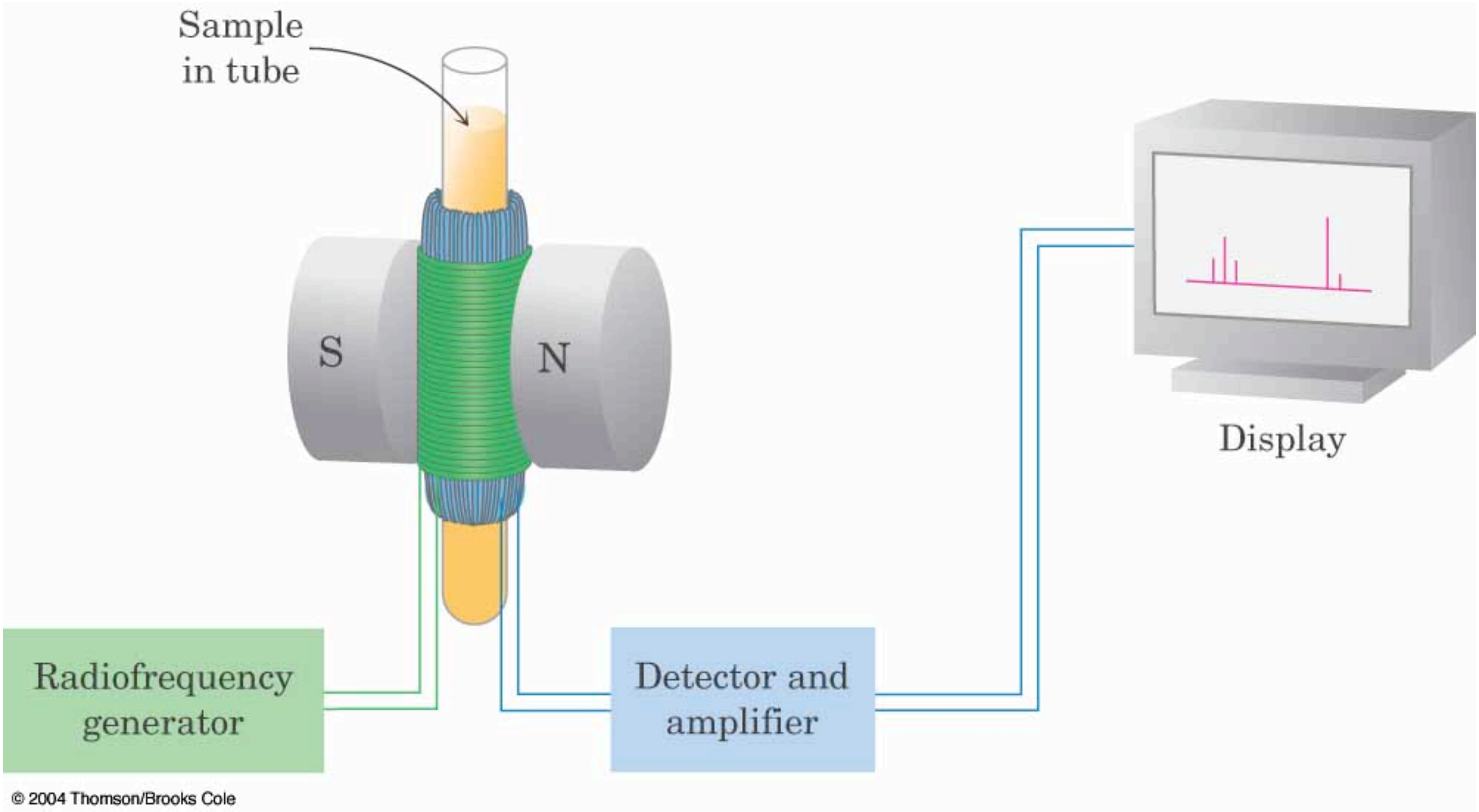
Energy difference between the states at a particular magnet strength. In the R_f range of the EM Spectrum.

When EM waves at this energy are directed at the nuclei - it will absorb. Spins will flip from lower energy to higher energy. At that energy, nuclei are "In Resonance".

NMR Active Nuclei

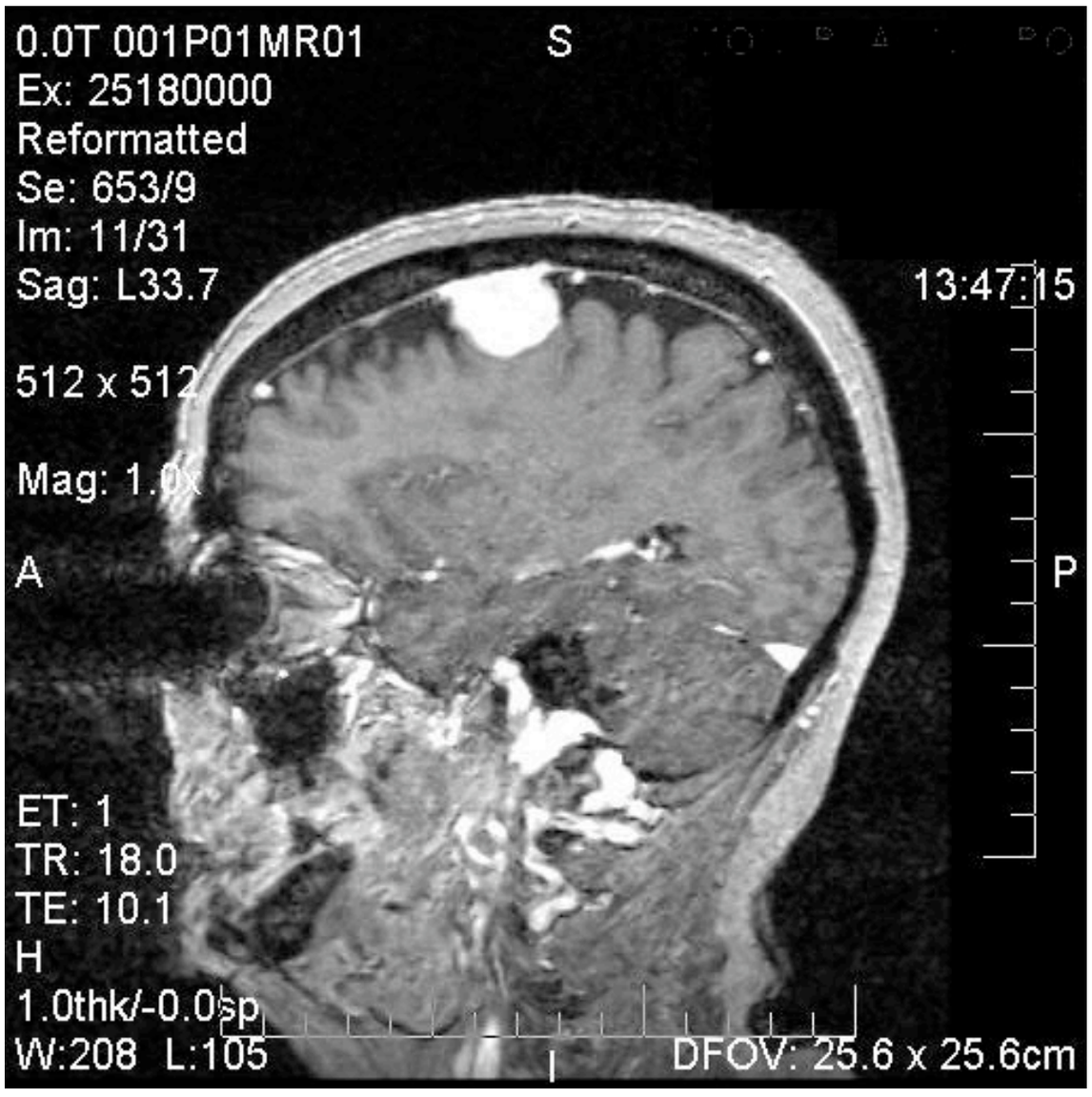
- Many nuclei are "NMR Active"
  - Spin Quantum Number $I \neq 0$
  - ^{1}H -- $I = ½$; ^{13}C -- $I = ½$
  - ^{12}C, ^{16}O -- $I = 0$ -- Can't be observed
- Other nuclei that are NMR active
  - ^{2}H (D), ^{14}N, ^{19}F, ^{31}P

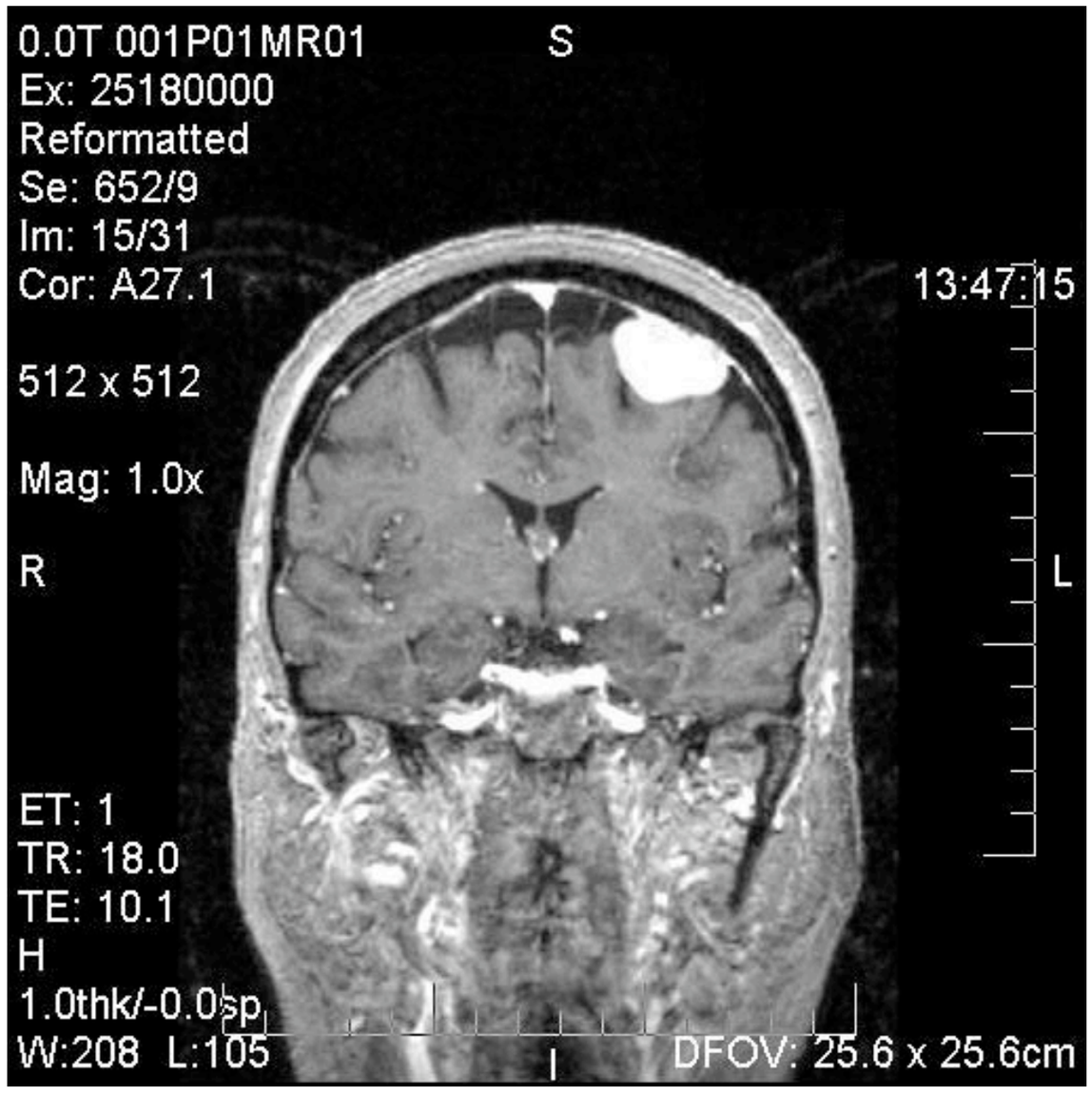
NMR Instrumentation



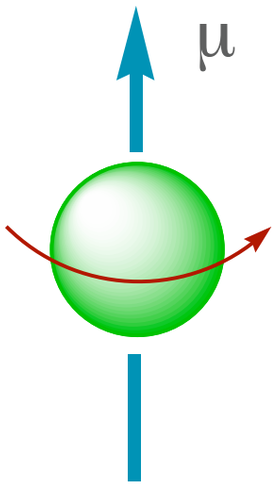
Magnetic Resonance Imaging

- NMR is the basis for MRI

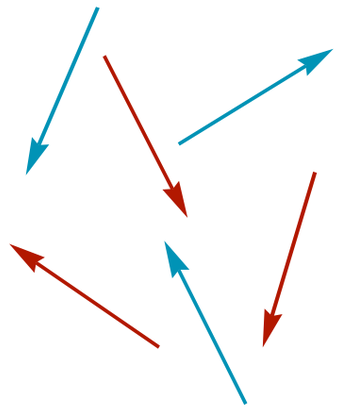




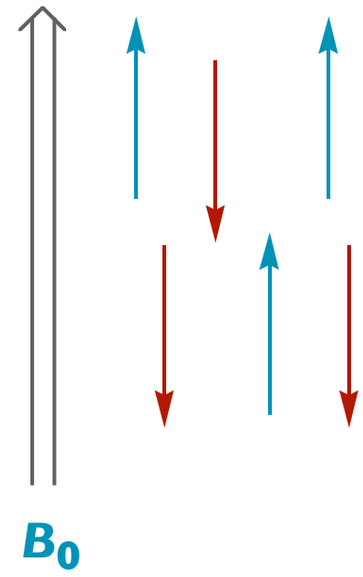
To summarize

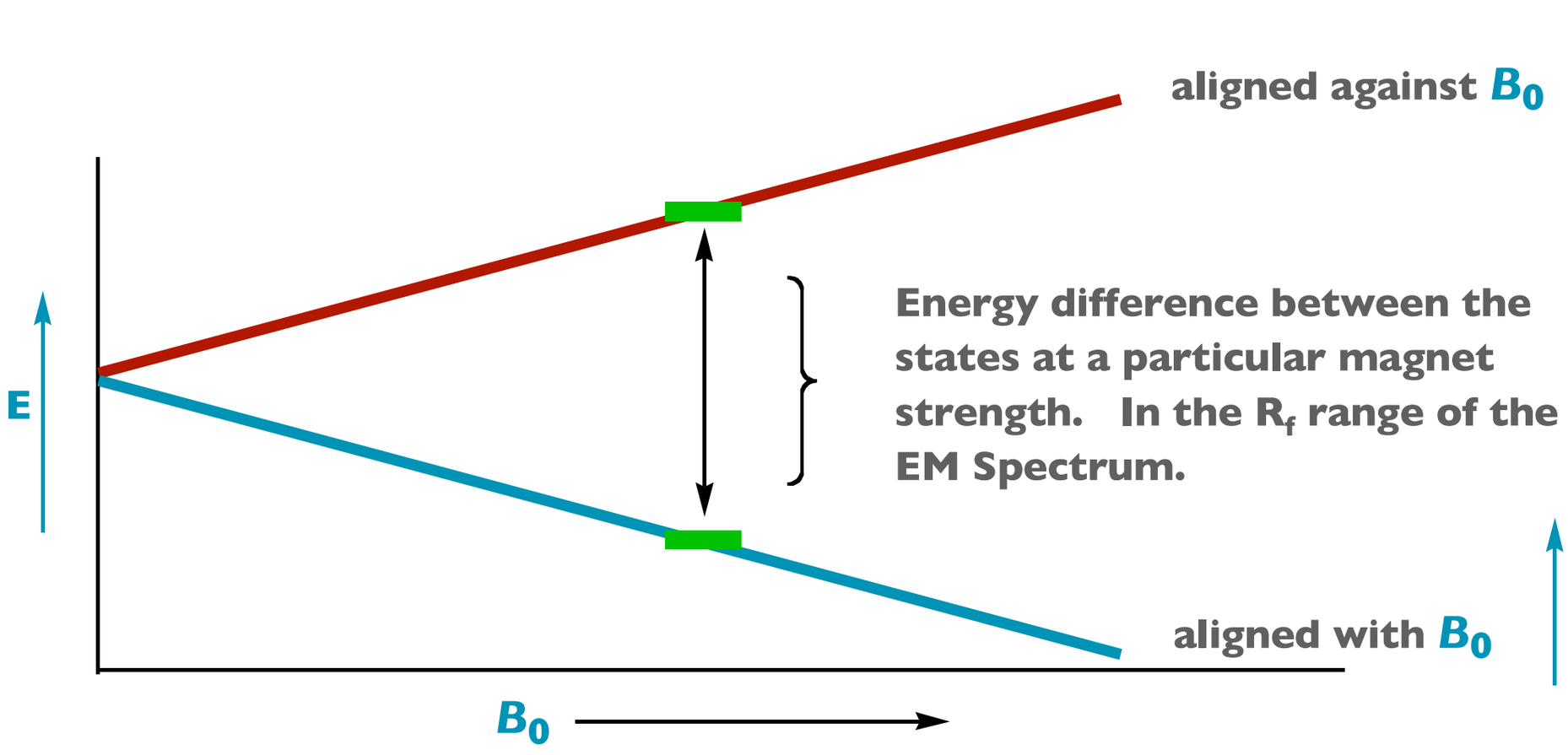


A spinning charged particle generates a magnetic field.
A nucleus with a spin angular momentum will generate a magnetic moment (m).

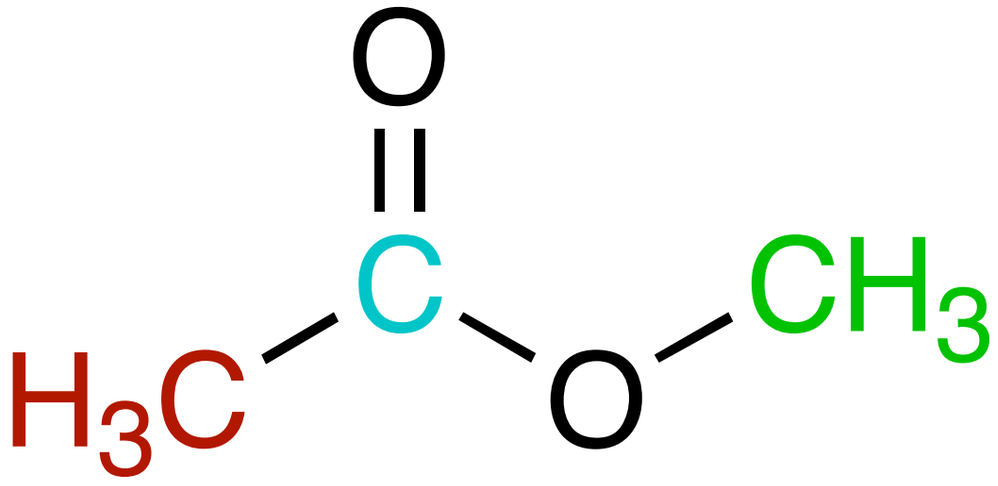


When placed in a magnetic field (***Bo***), they will adopt two different states - one aligned with the field and one aligned against the field.

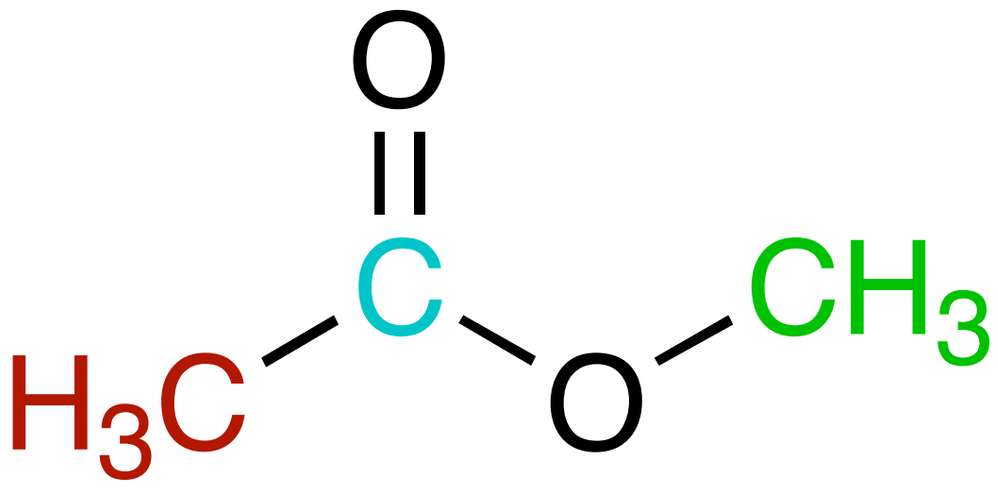




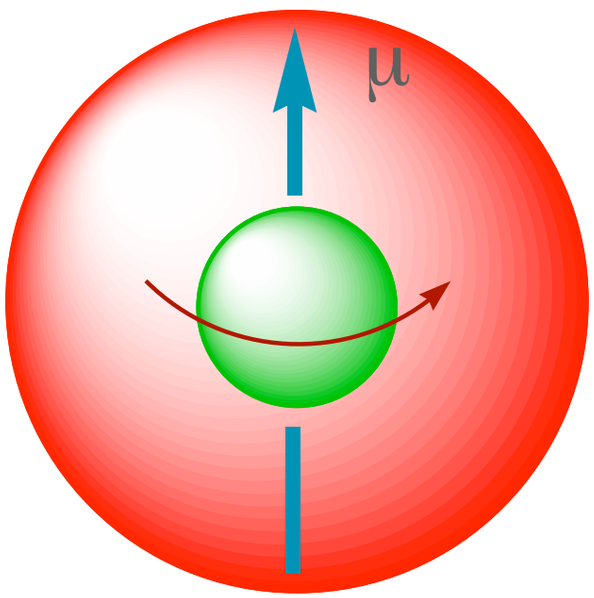
Methyl Acetate - Proton NMR

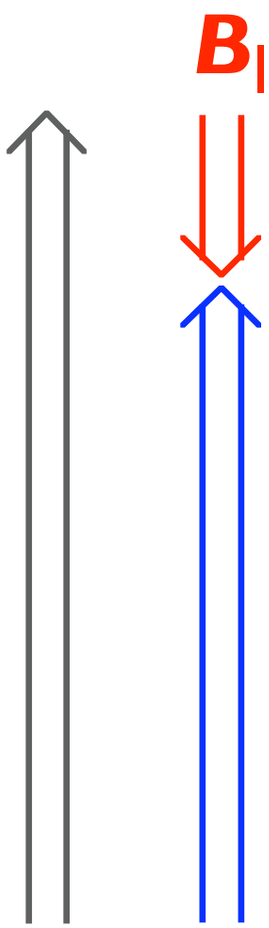


Methyl Acetate - Carbon NMR



Electronic Shielding - Local Environments

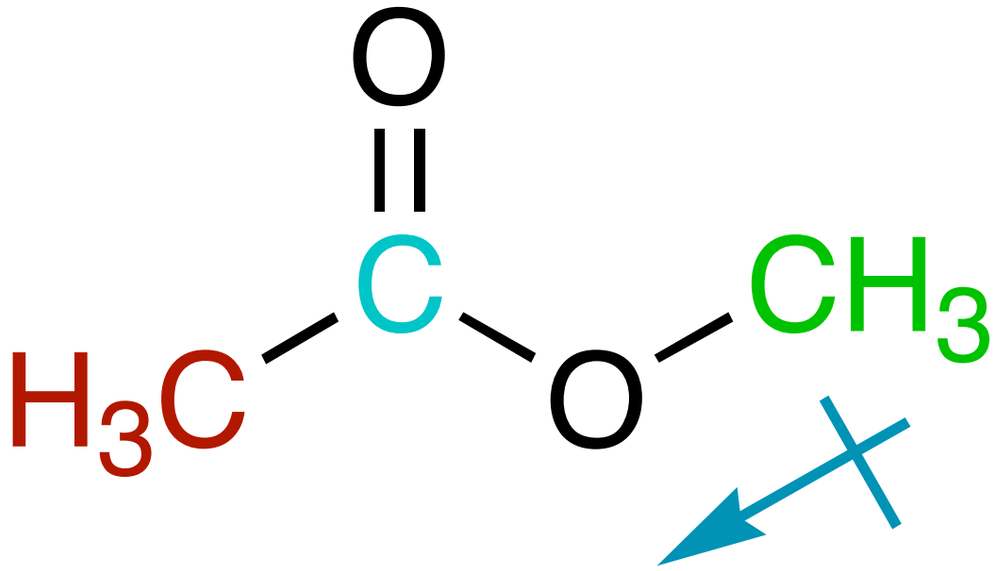




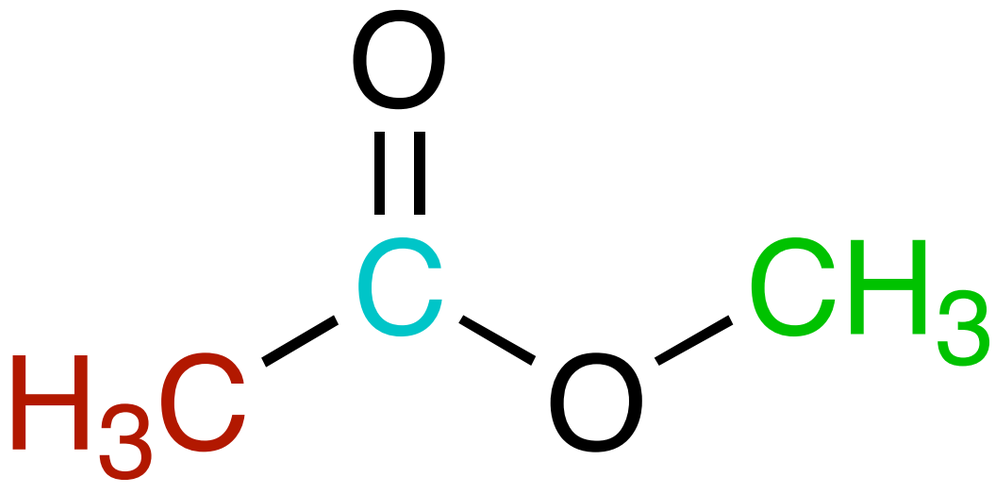
$$B_{effective} = B_0 - B_{local}$$

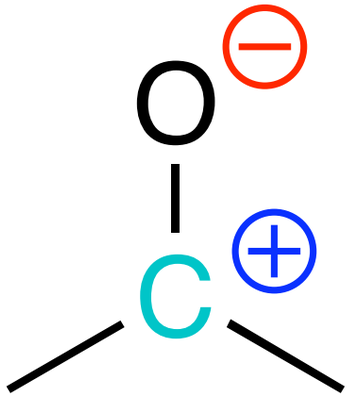
Actual magnetic field felt by the nucleus

Methyl Acetate - Proton NMR



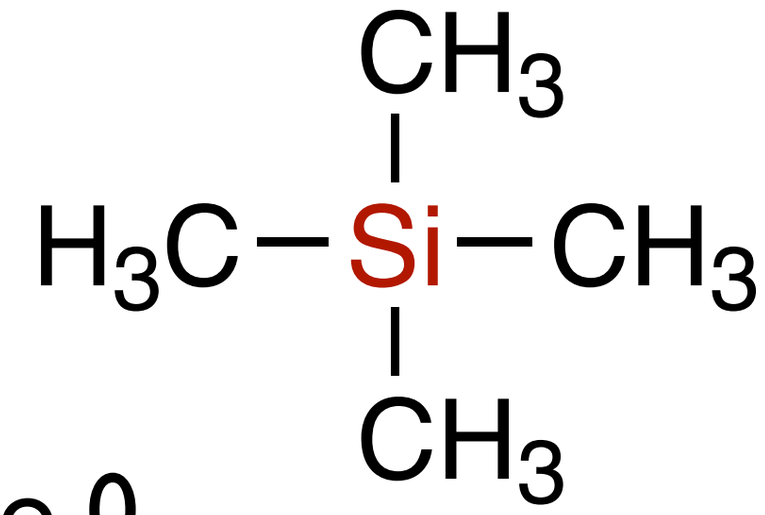
Methyl Acetate - Carbon NMR





Chemical Shift

- The difference in resonance frequency of a nuclei relative to a standard
  - Most Shielded
  - Relatively Inert
  - Volatile
- Resonance of standard is set to 0



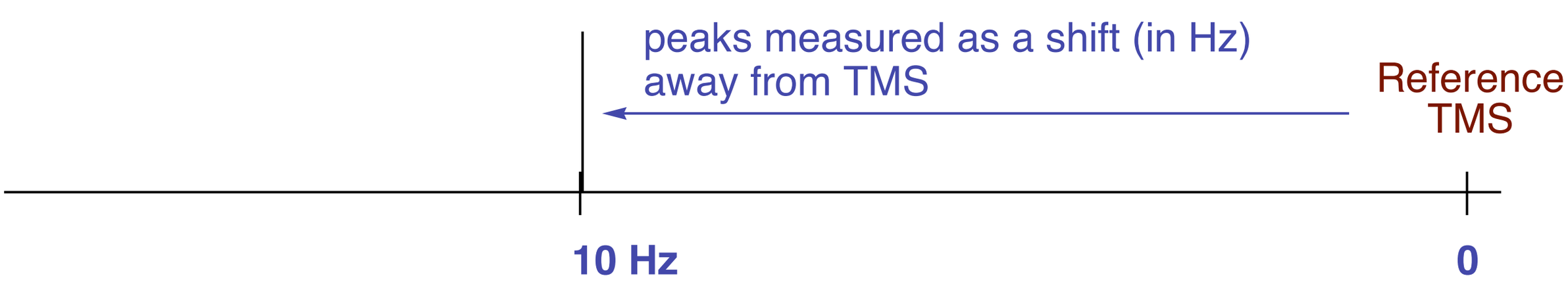
TMS
TetraMethylSilane

NMR Scale

- X-Axis - frequency axis

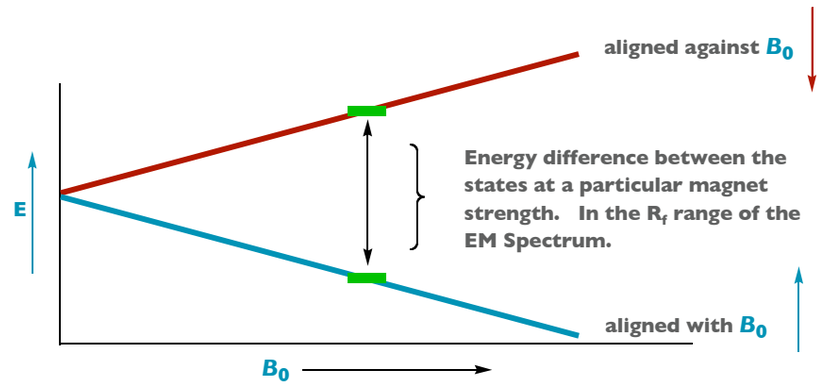
NMR Spectrum

Low Field **Little electron shielding** (more electron withdrawing groups)	**High Field** **More electron shielding** (less electron withdrawing groups)



Different Spectrometer Frequencies

- Each specific instrument has it's own magnetic field strength - resonace occurs at different frequencies.



100 MHz NMR
300 MHz NMR

Standard Scale

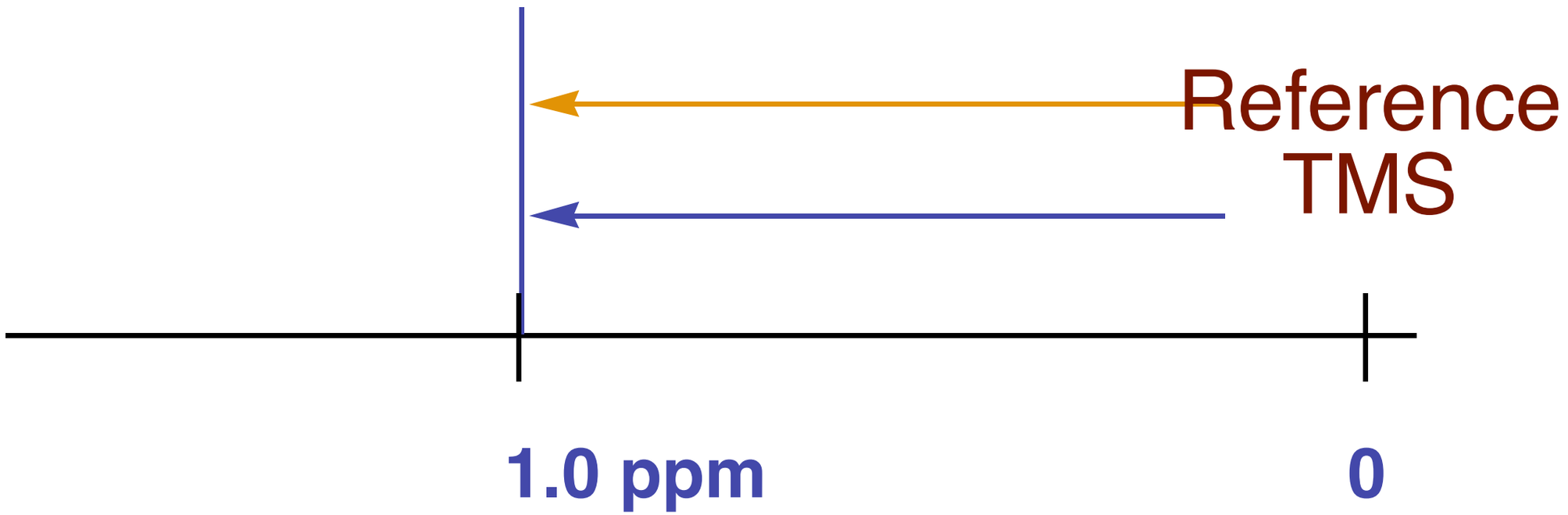
- δ = ppm = $\dfrac{\text{Chemical Shift from TMS (Hz)}}{\text{Spectrometer Frequency (MHz)}}$

100 MHz NMR

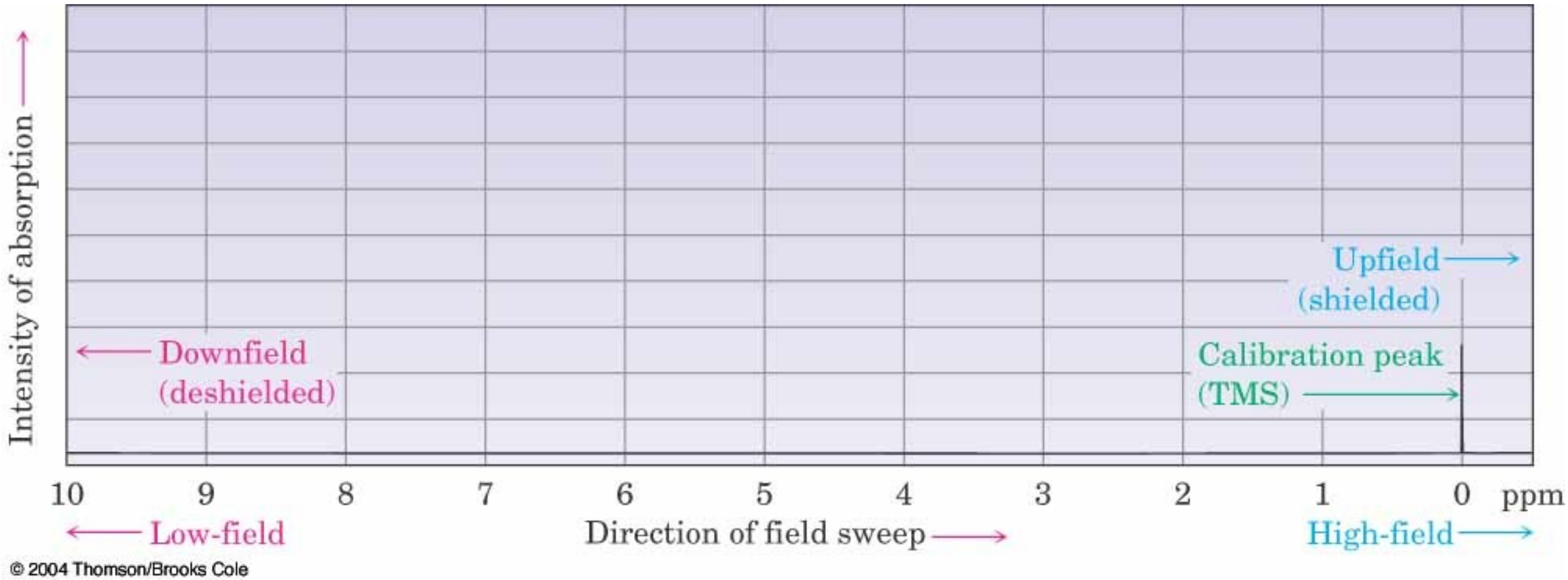
$\dfrac{100\ \text{Hz}}{100\ \text{MHz}} = 1.0\ \text{ppm}$

300 MHz NMR

$\dfrac{300\ \text{Hz}}{300\ \text{MHz}} = 1.0\ \text{ppm}$

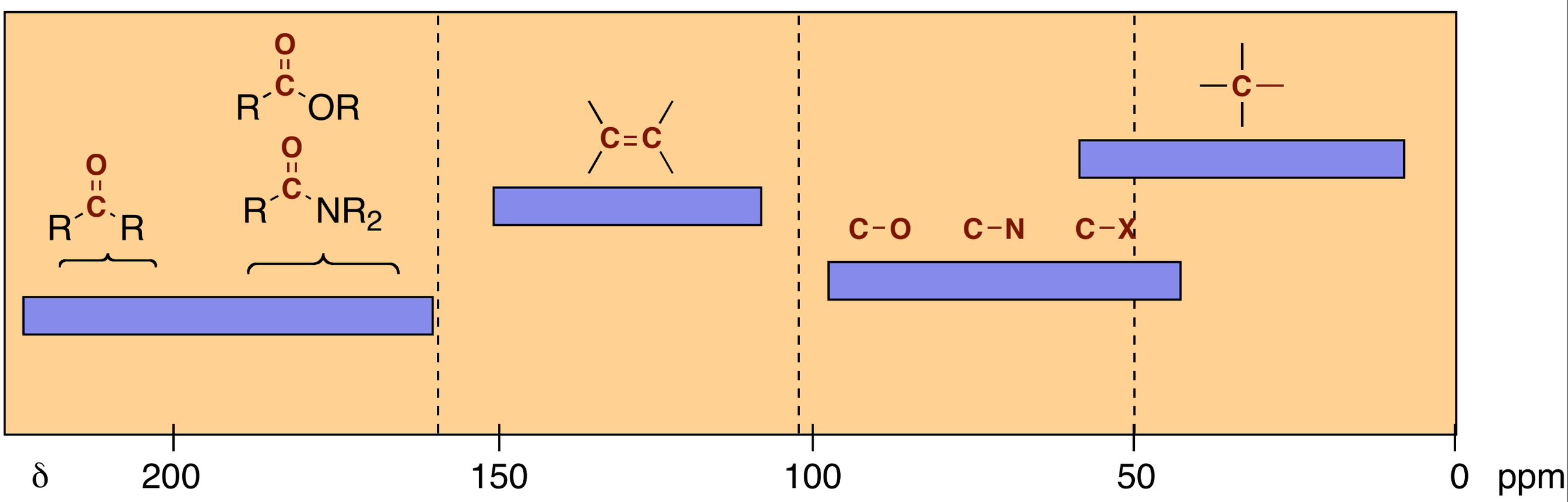


NMR Scale

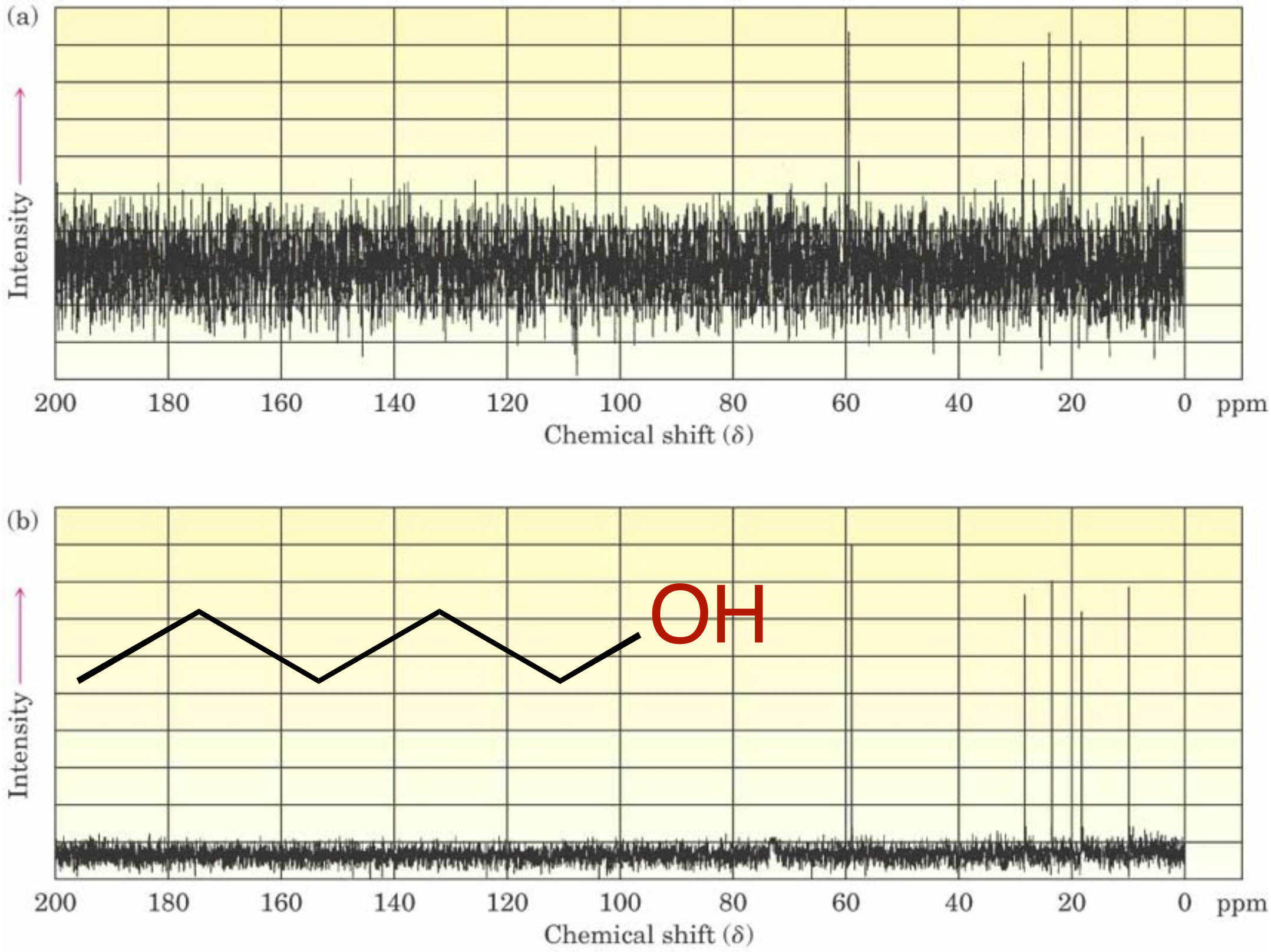


C13 NMR

- Difficult - Carbon 13 only 1.1% of all carbon.
- Number of different carbons
- Functional Group Regions

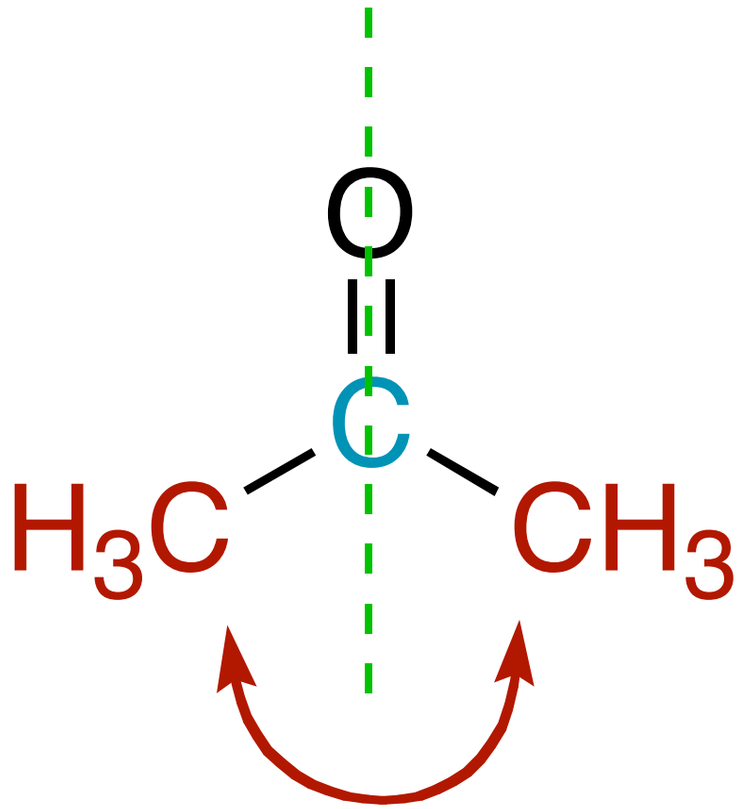


C13 NMR

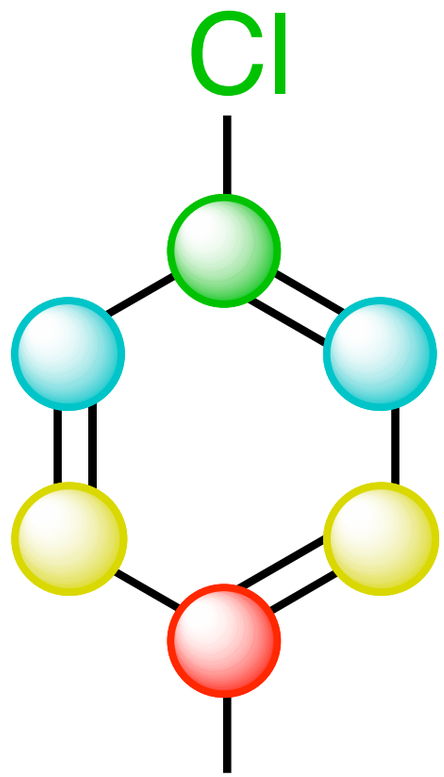

(a)
Intensity
200
180
160
140
120
100
80
60
40
20
0
ppm
Chemical shift (δ)
(b)
OH
Intensity
200
180
160
140
120
100
80
60
40
20
0
ppm
Chemical shift (δ)

Symmetry

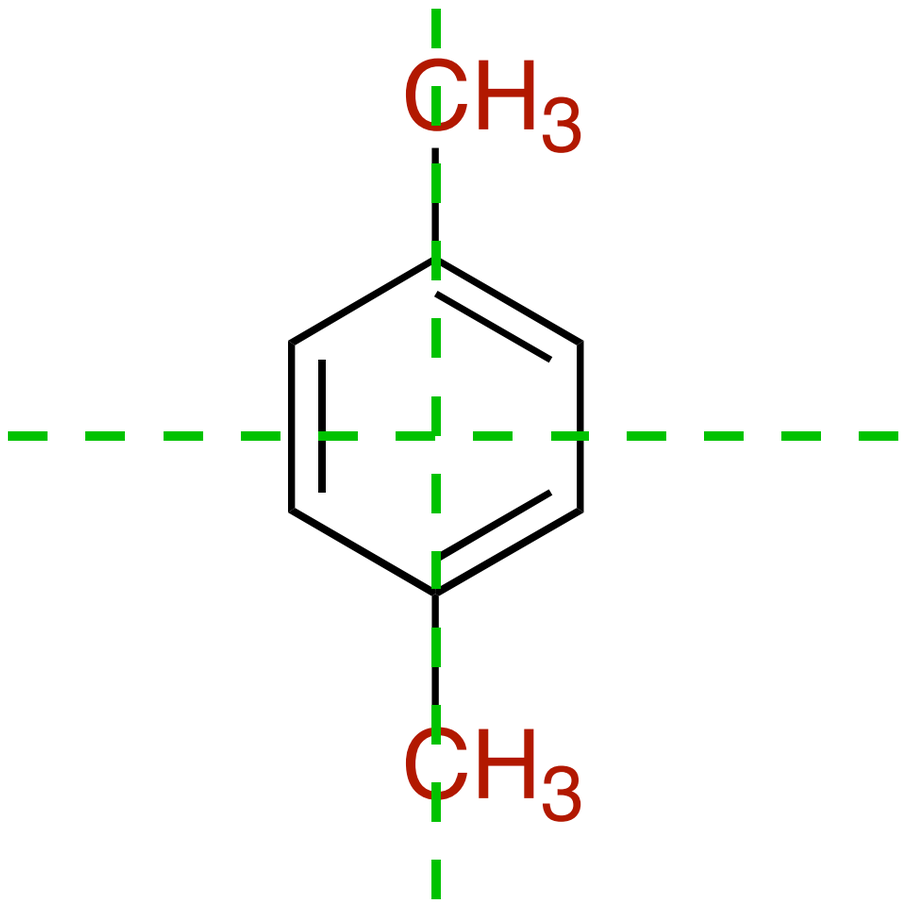
- Symmetry in molecules can make carbons "Chemically Equivalent"

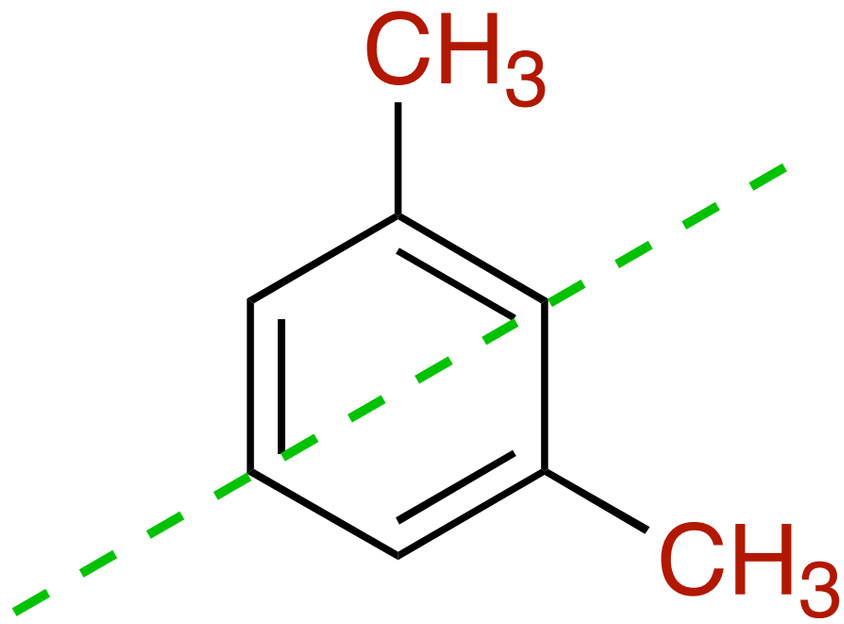


same electronic environment

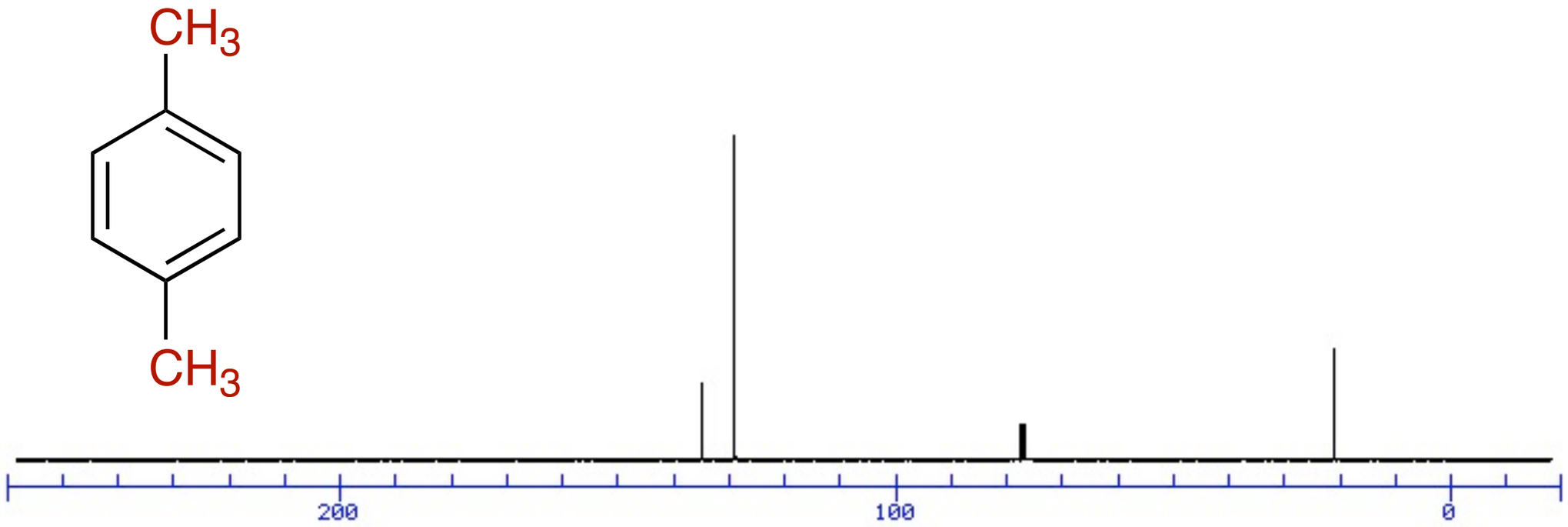


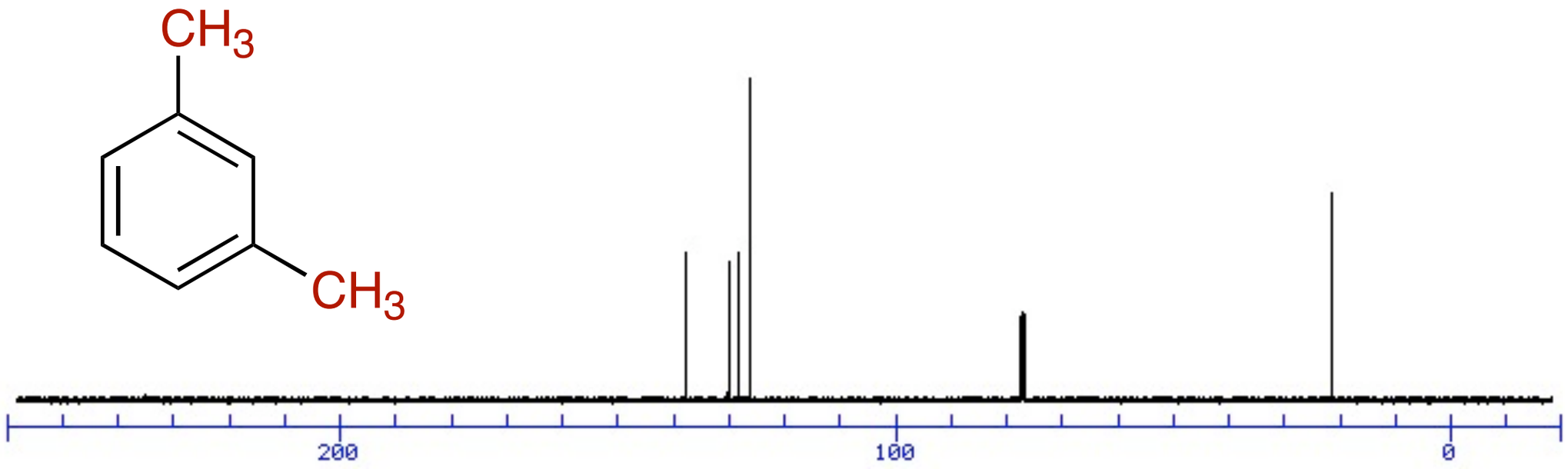
- Some molecules have more than one mirror plane



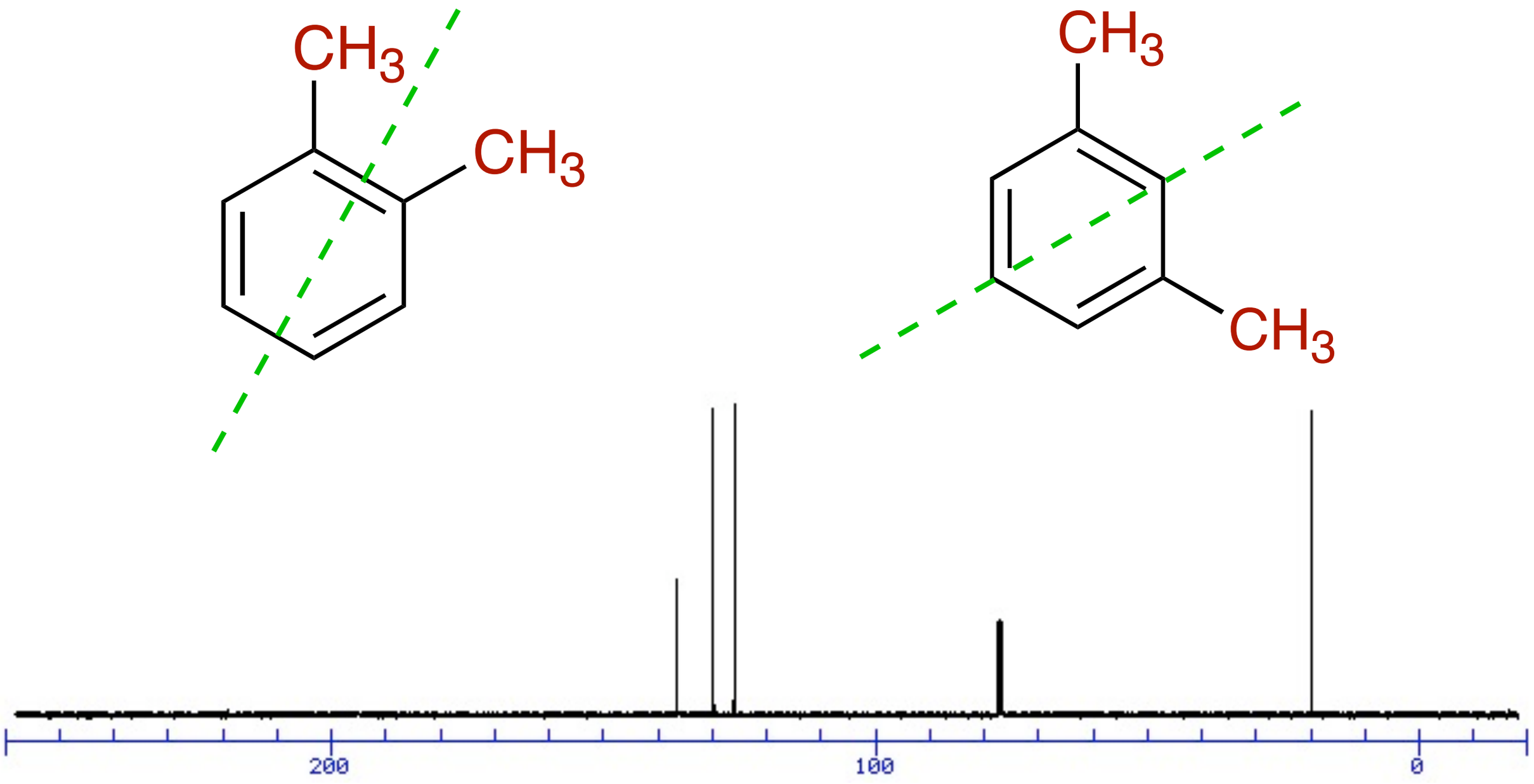


Symmetry



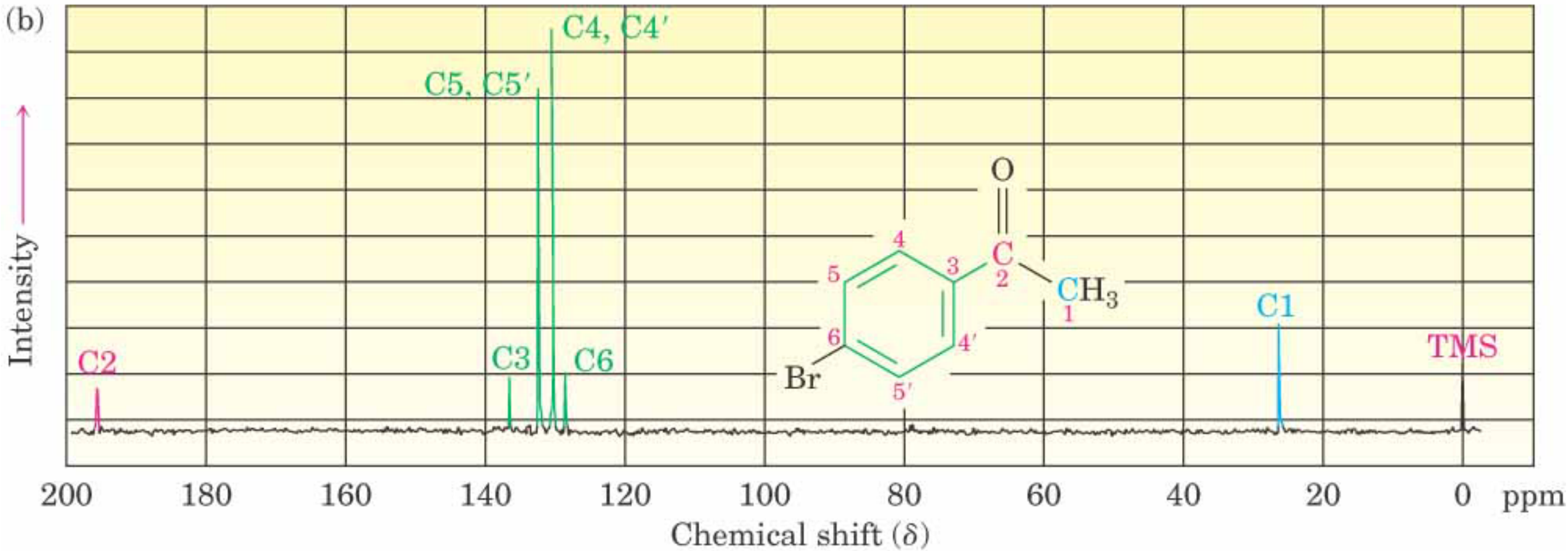


Symmetry



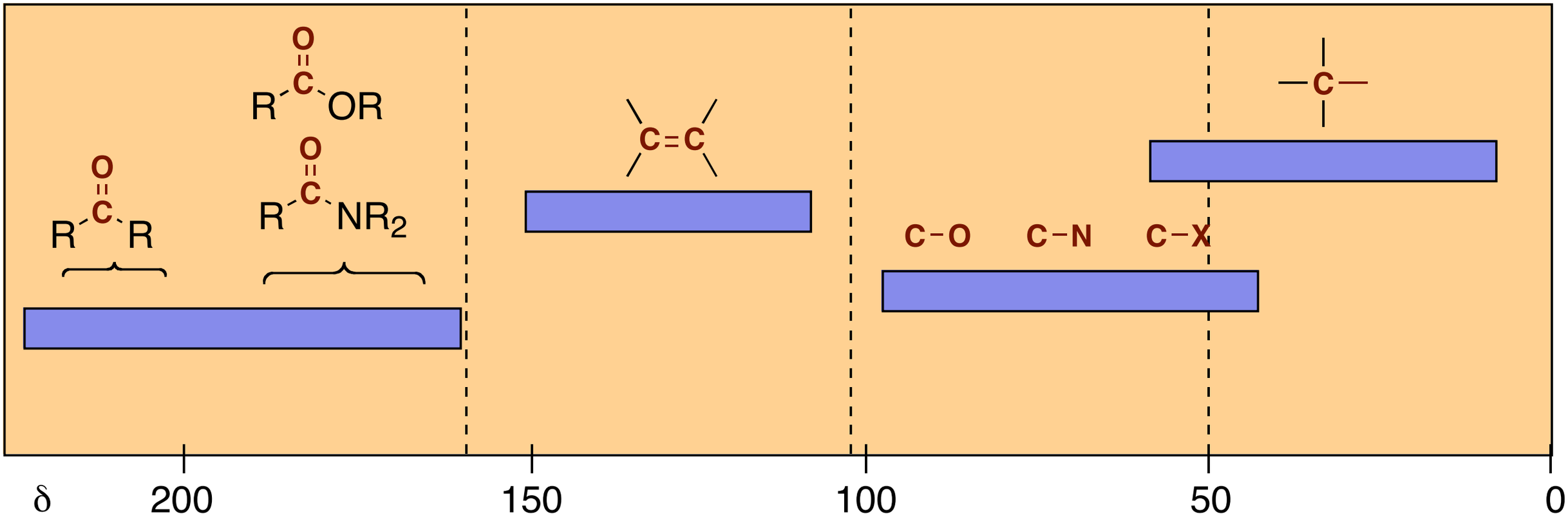
Substitution of Carbon

- The intensity of the peaks roughly correlates with the number of hydrogens on the carbon.

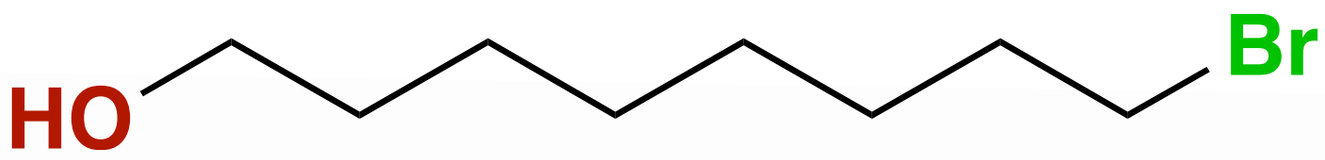


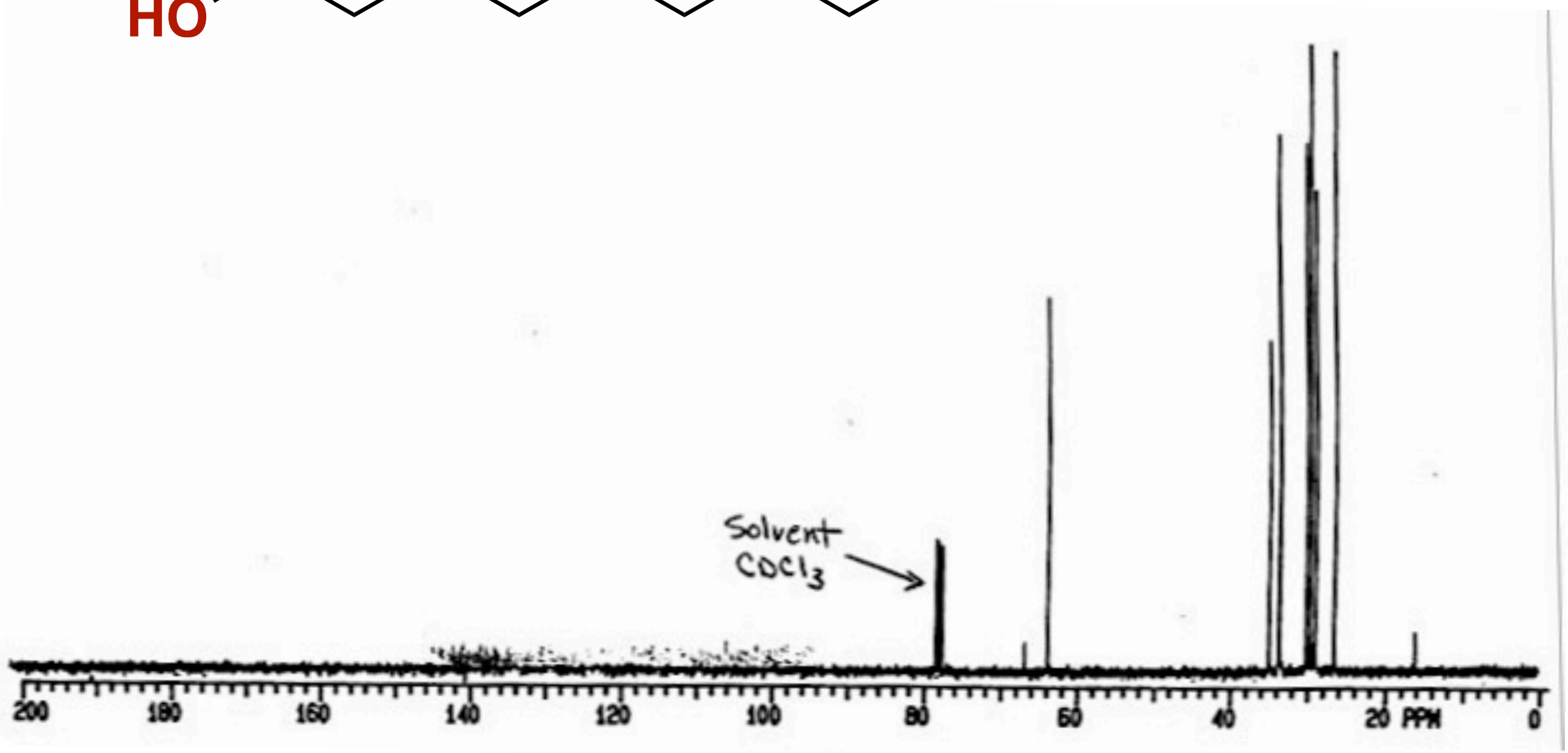
C13 NMR Regions

^{13}C NMR

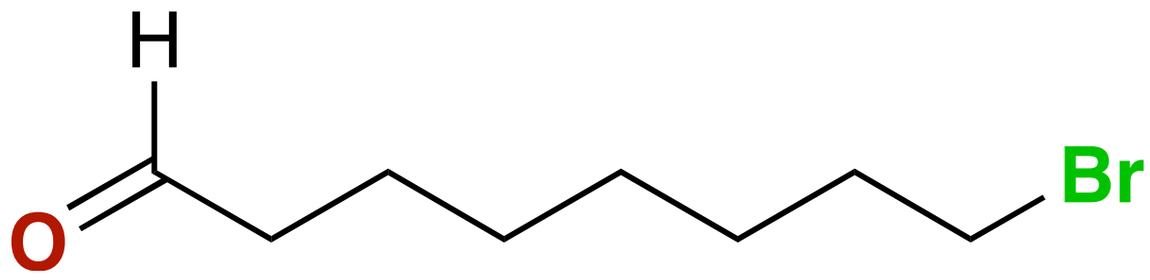


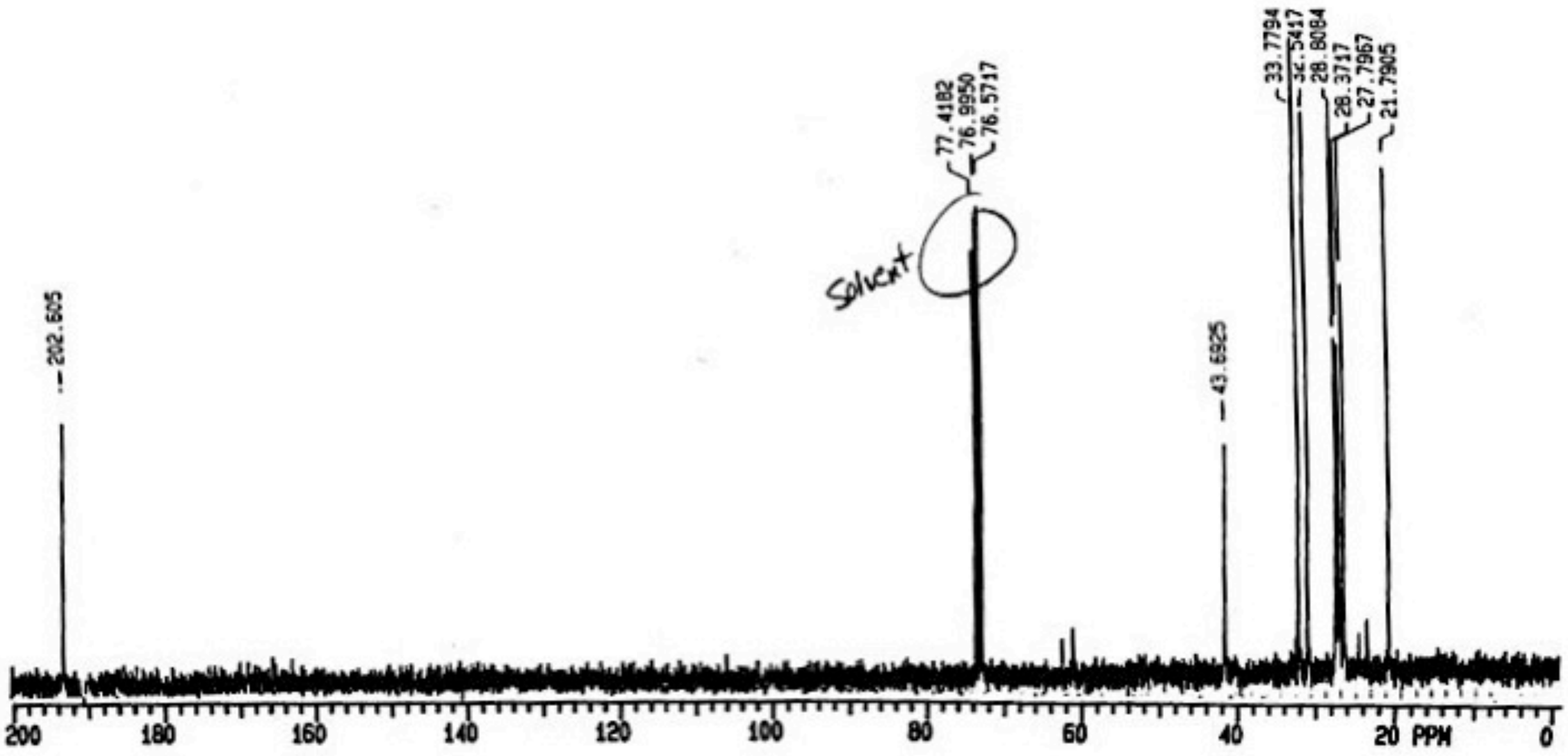
Bromooctanol



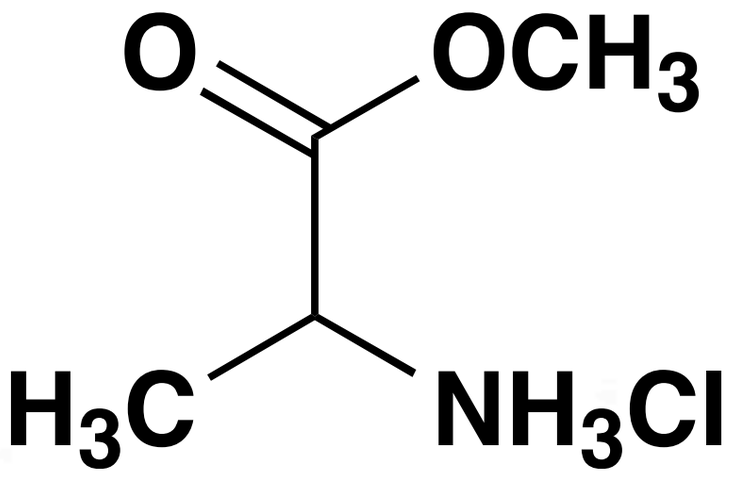


Bromooctanal

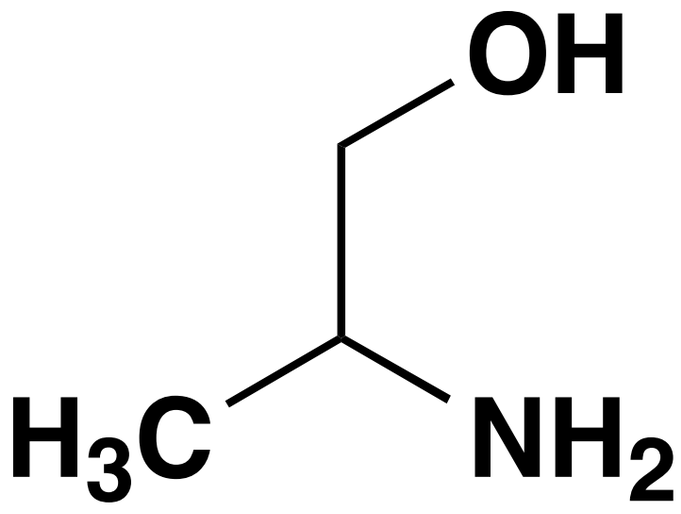




Alanine Me-Ester HCl

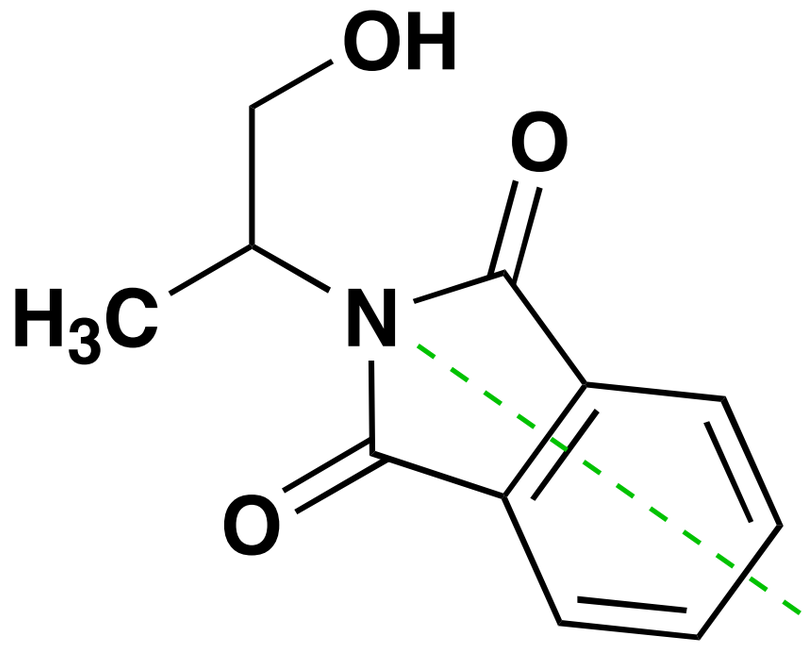


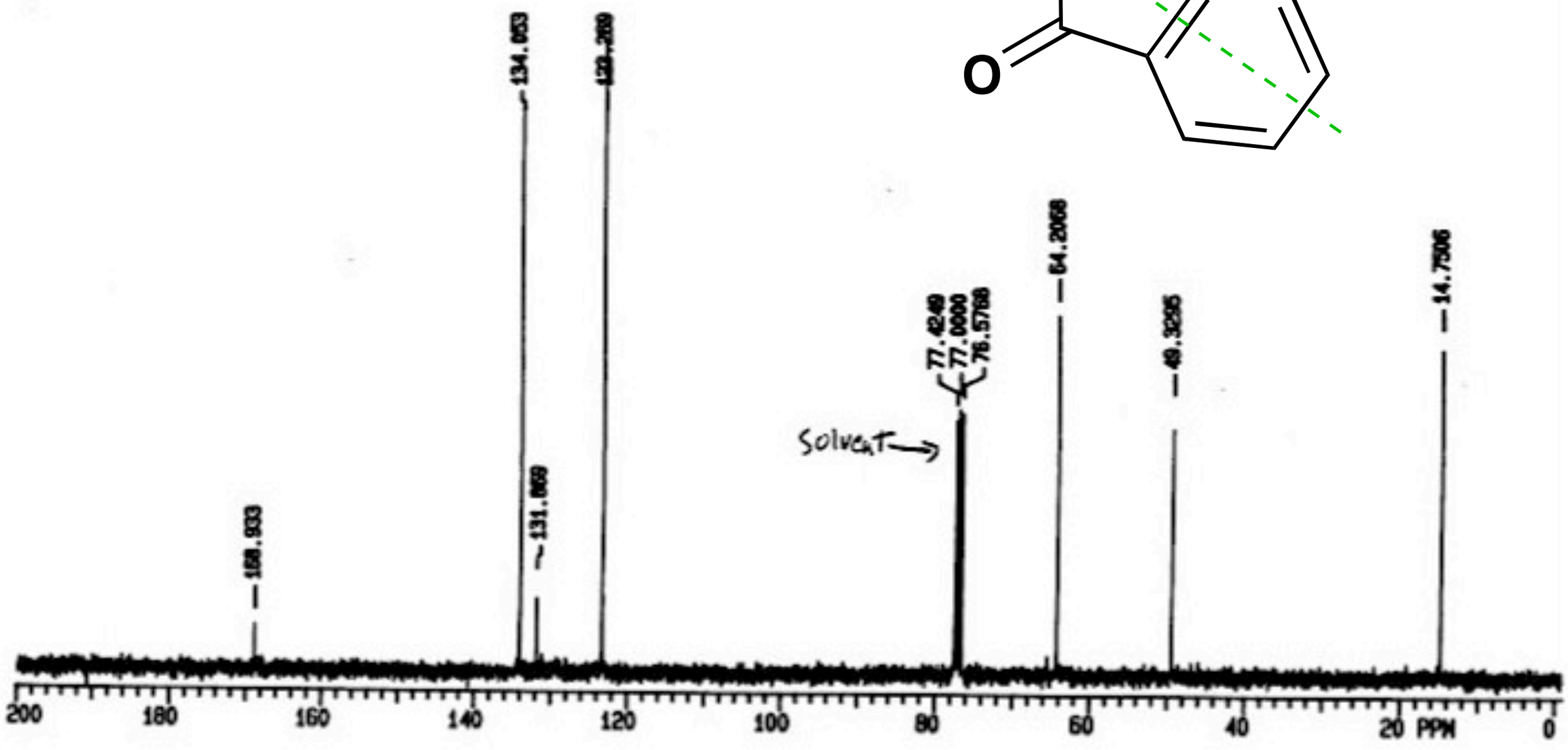
Alaninol


OH
H_3C
NH_2

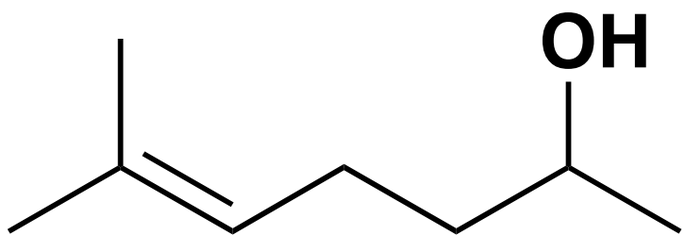
67.7866
48.2065
19.4214
77.4317
77.0067
76.5835
solvent
200
180
160
140
120
100
80
60
40
20
PPM
0

Alaninol - phthalimide

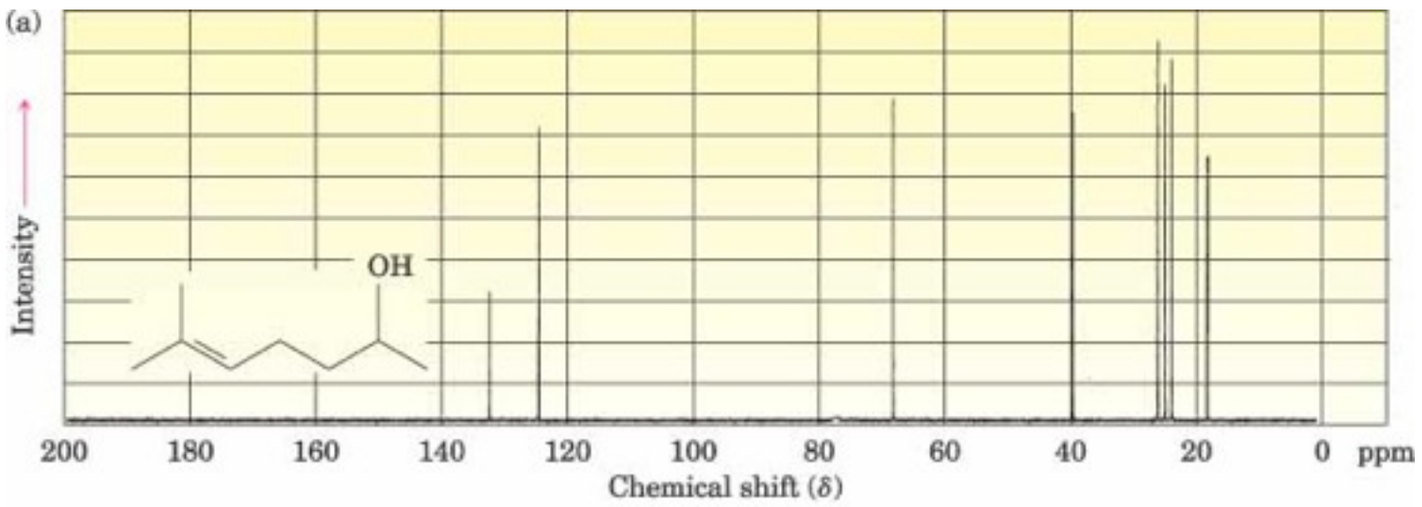


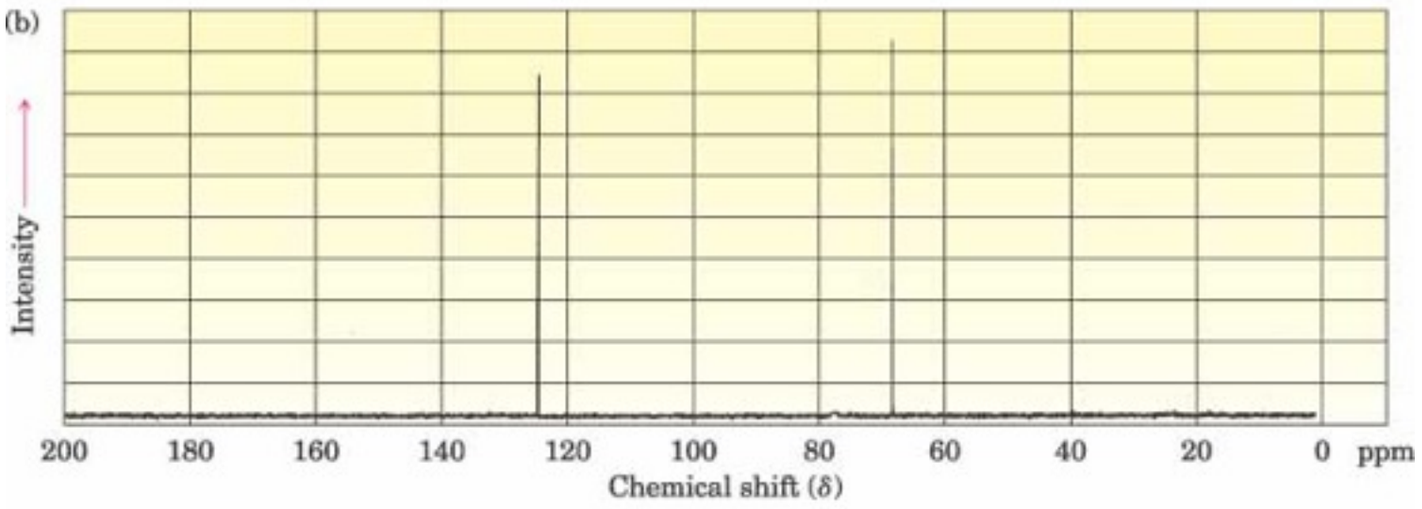


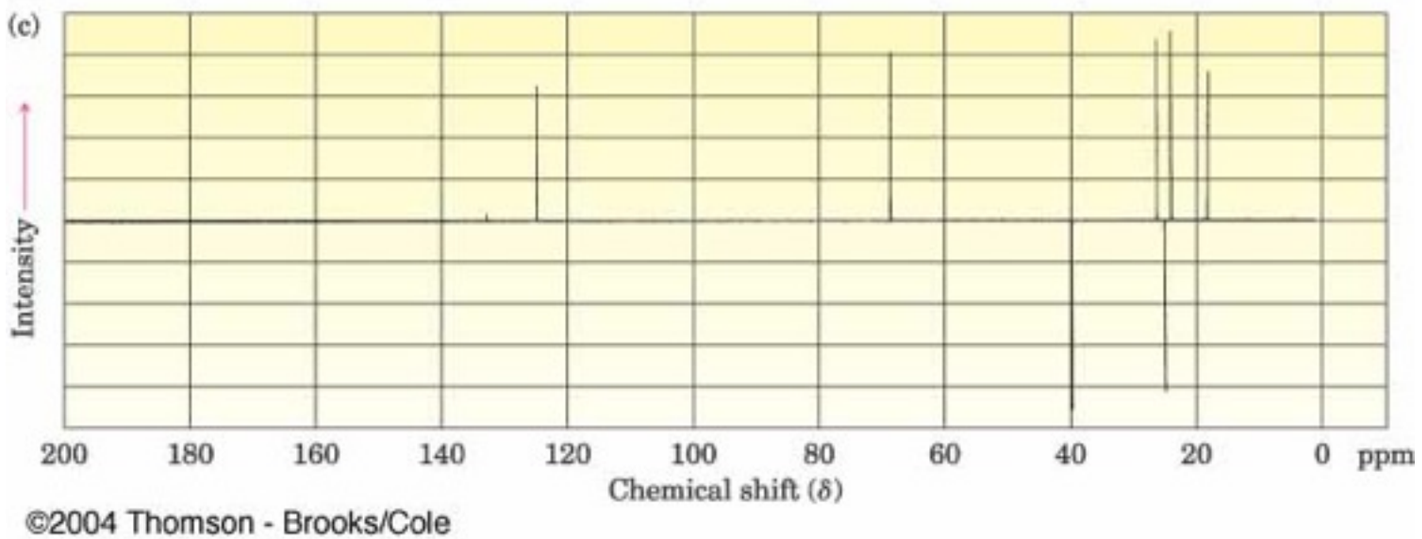
DEPT-C13



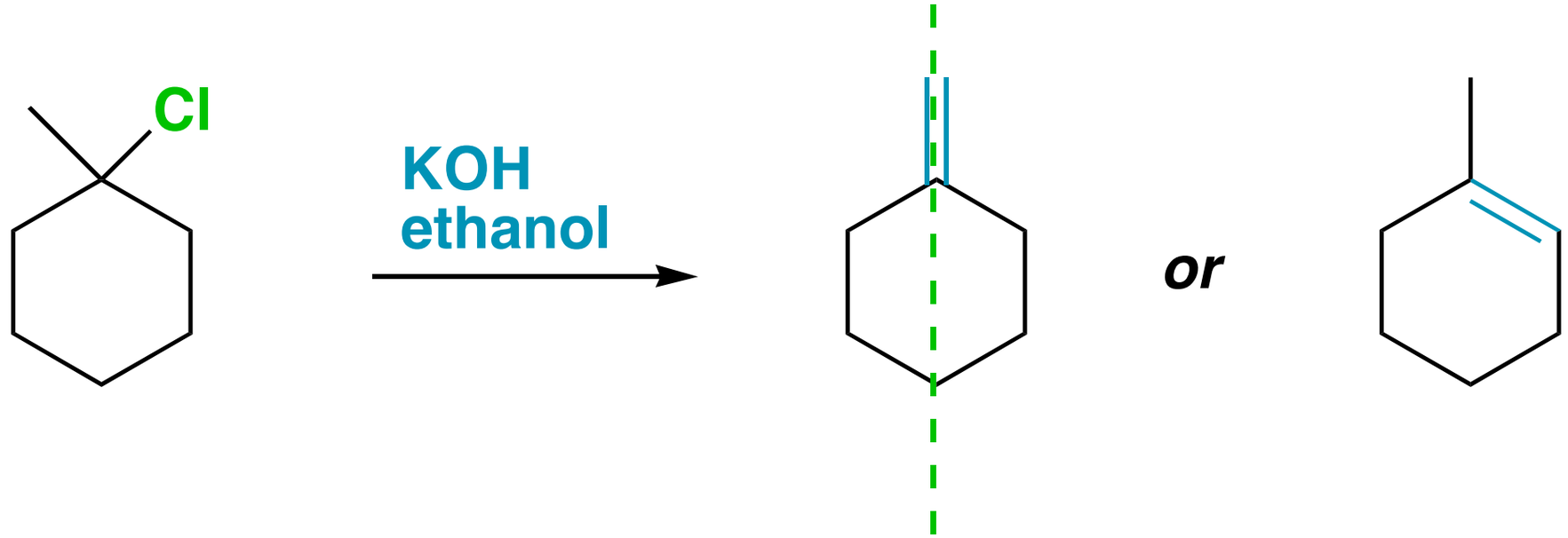
- A - normal C13
- B - CH carbons only
- C - Odd # up (CH3 and CH) Even # down (CH2)

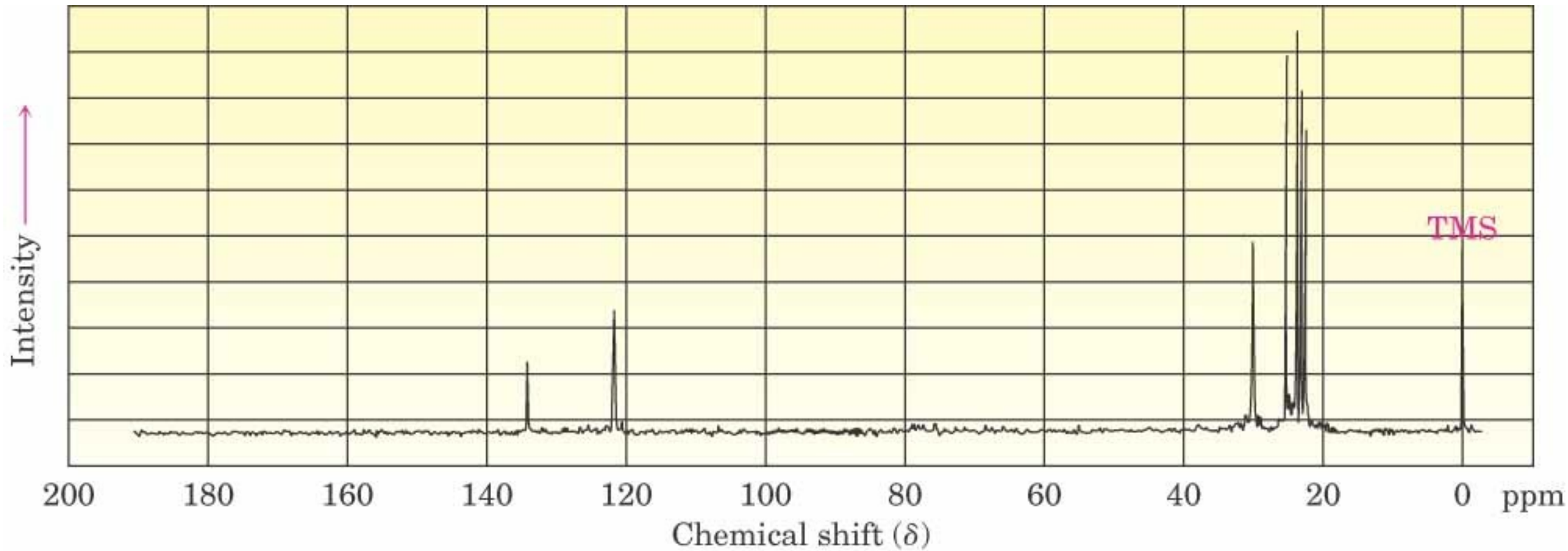




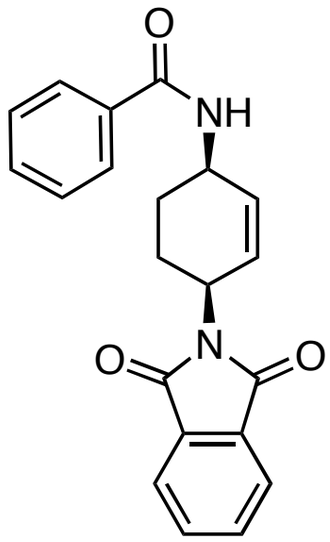


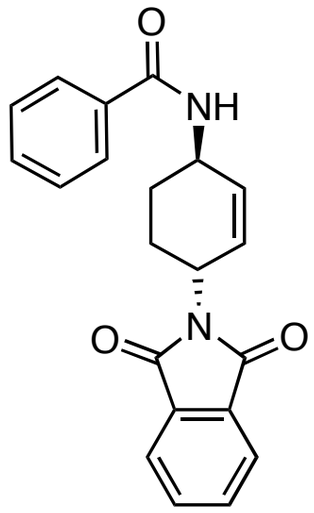
Example from 13.7



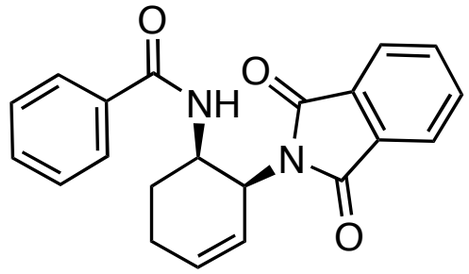


A Real Example

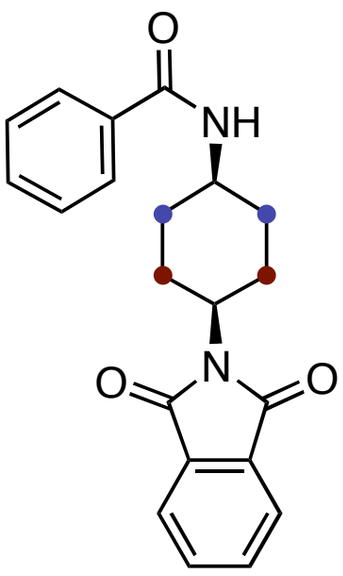




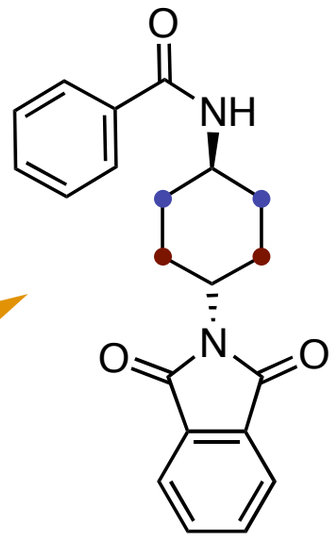
OR



H_2, Pd/C

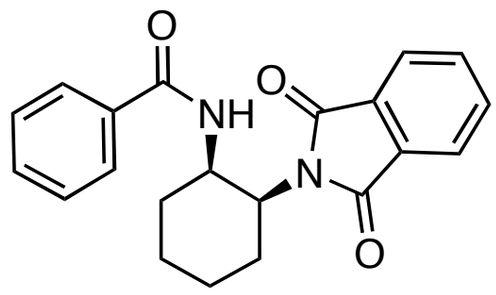


In the alkane region there would only be 4 peaks due to symmetry



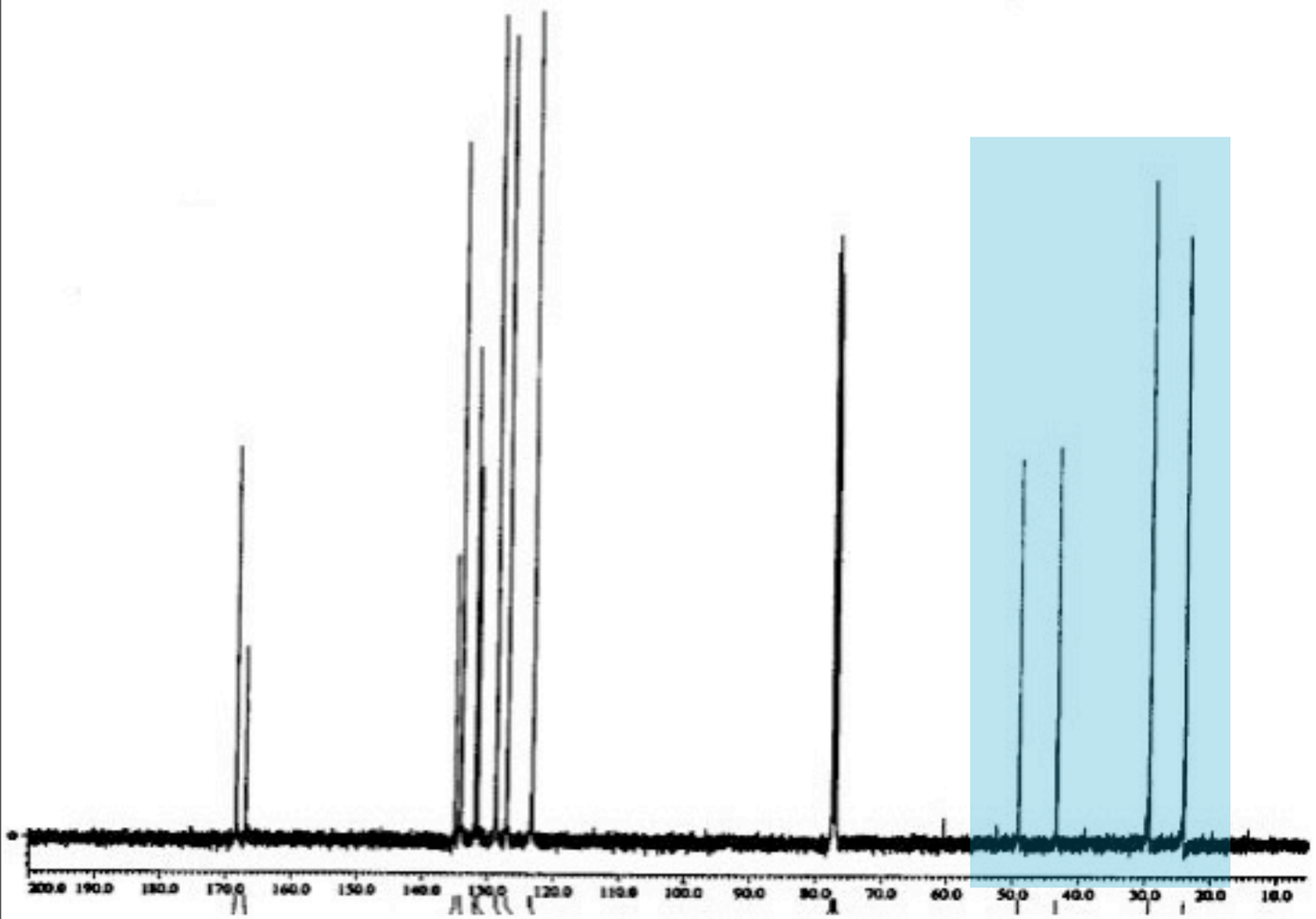
OR

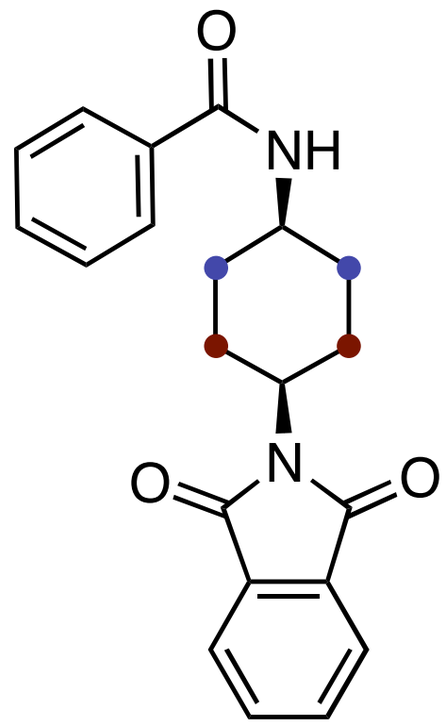
H_2, Pd/C

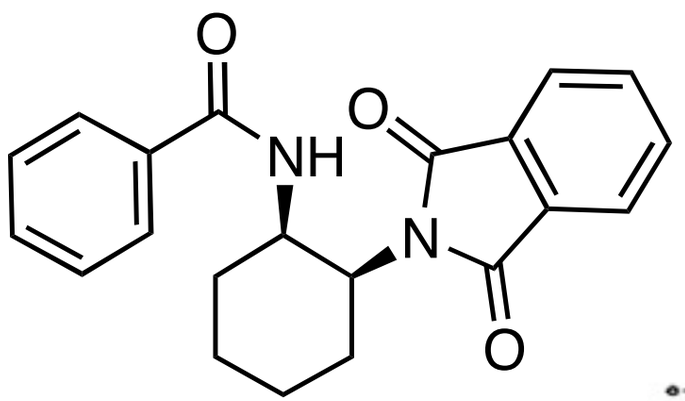


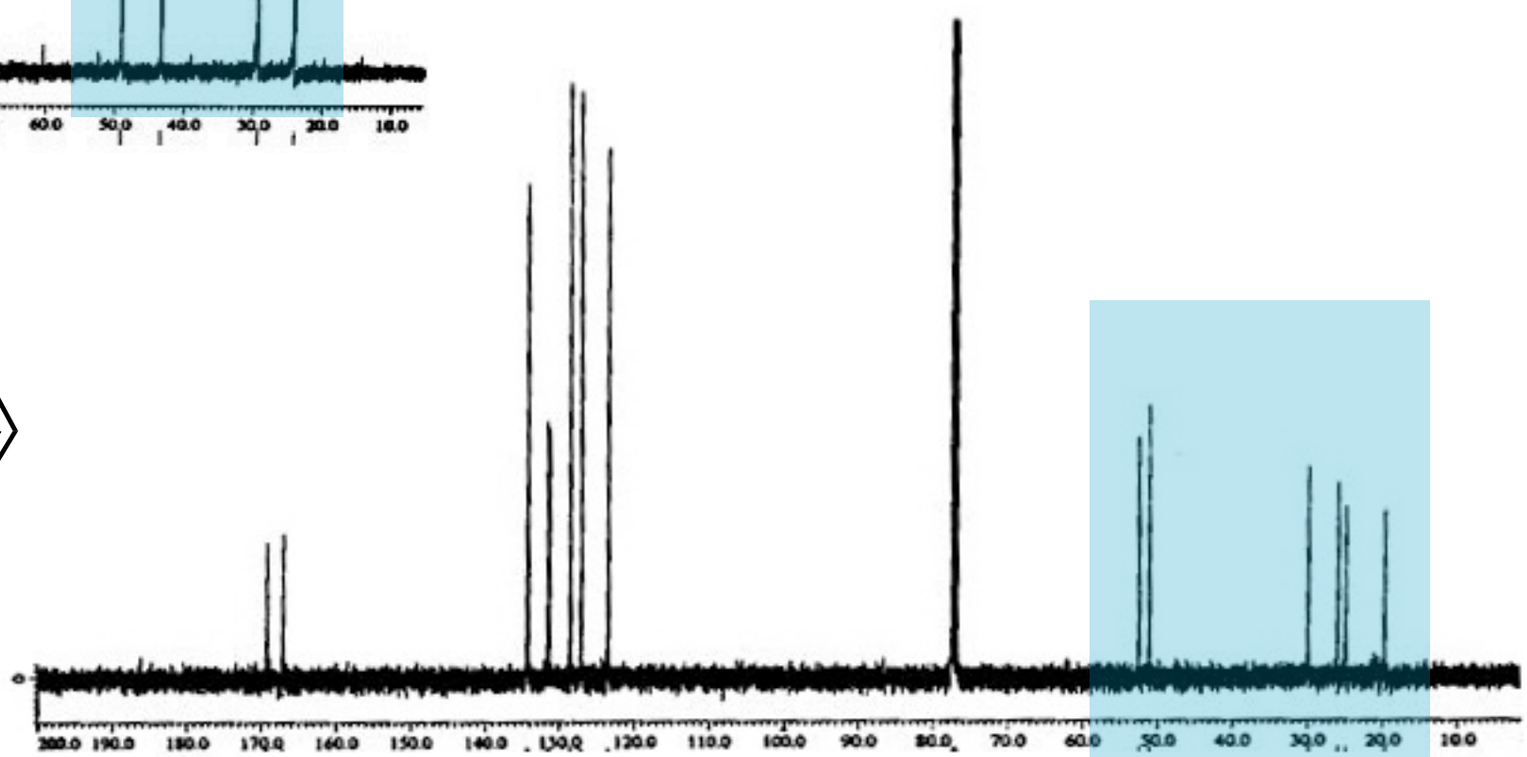
In the alkane region there would be 6 different peaks

The Answer Is . . .







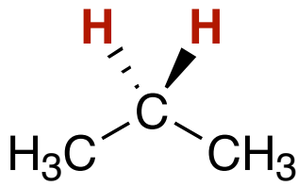


Proton NMR

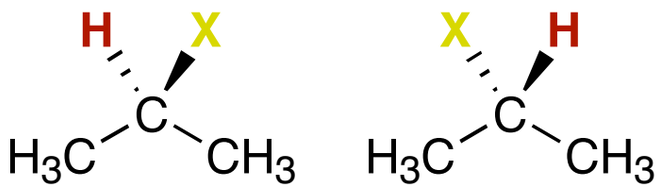
- Number of chemically different hydrogens
- Relative Ratios of protons (peak size)
- How many neighboring hydrogens
- Chemical shifts and functional groups

Proton Equivalency

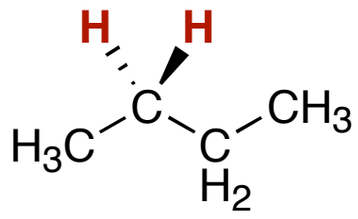
Homotopic



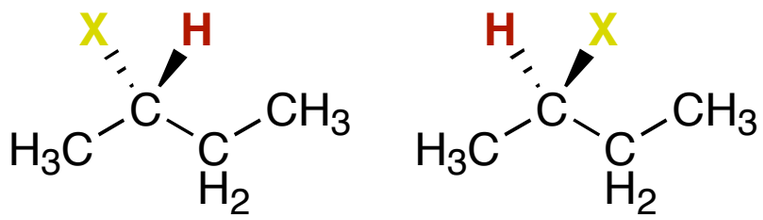
replace H's - same



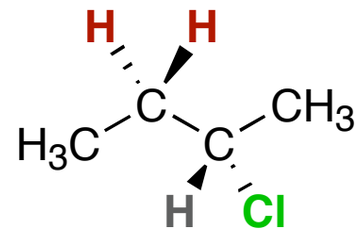
Enantiotopic



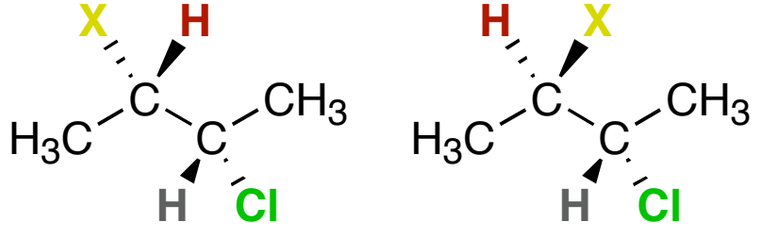
replace H's - enantiomers



Diastereotopic

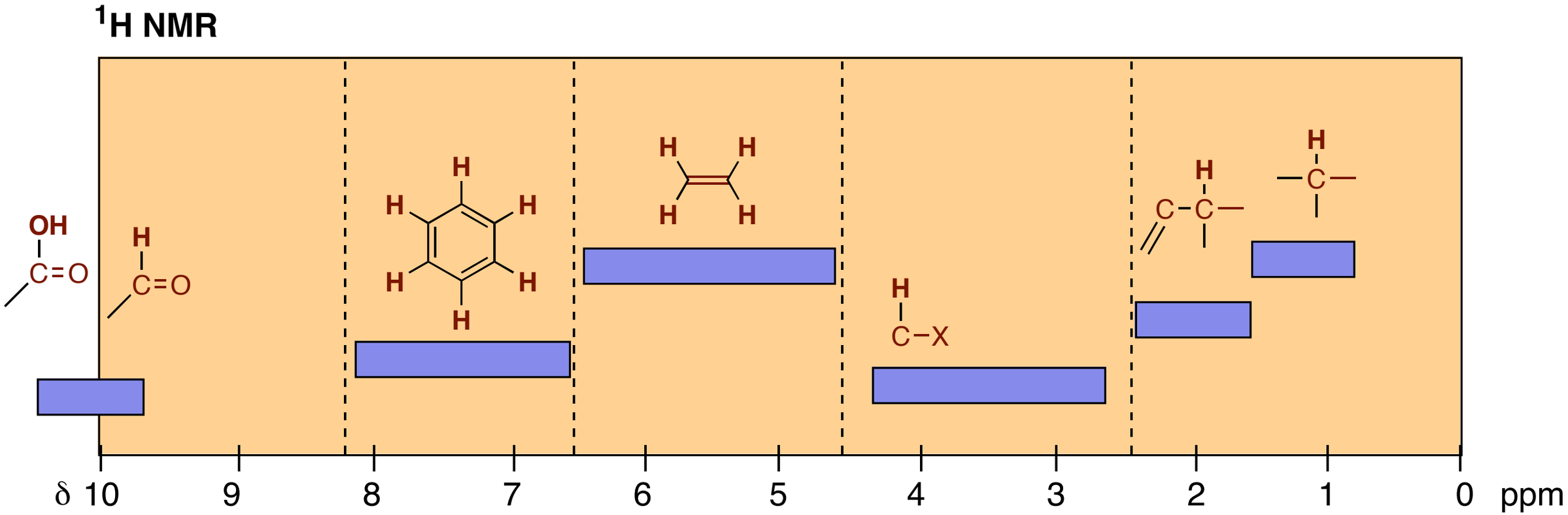


replace H's - diastereomers



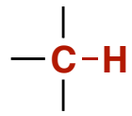
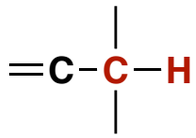
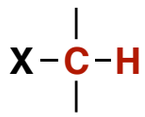
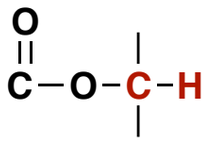
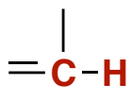
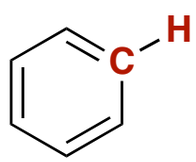
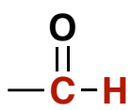
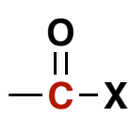
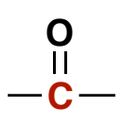
Proton NMR Scale

- Range 0-10 ppm

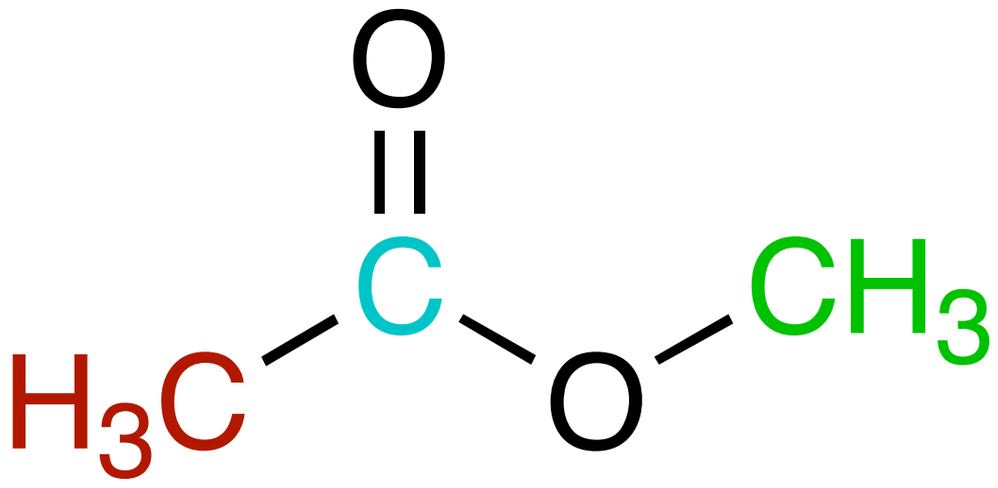


NMR Correlation Chart

Typical NMR Chemical Shifts

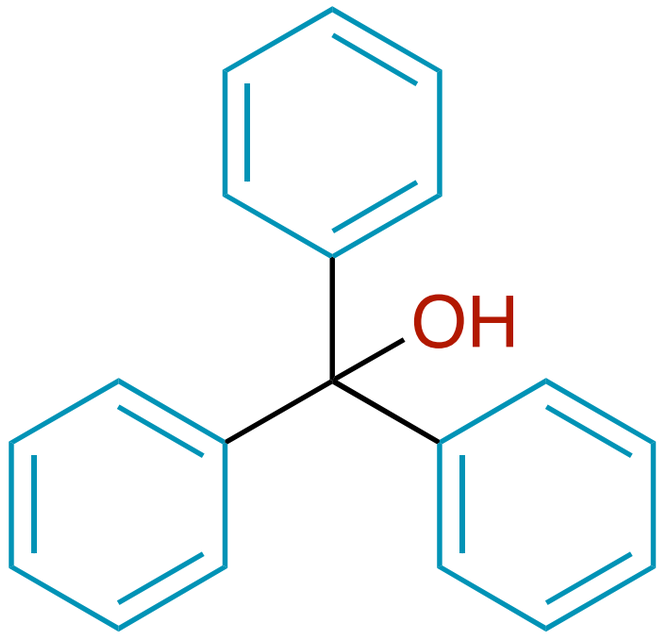
Functional Group	Type	^{1}H Chemical Shift (ppm)	^{13}C Chemical Shift (ppm)
	Alkane	0.7 -1.8	10 - 60
	Allylic or next to carbonyl	1.6 - 2.4	30 - 60
	next to halogen or alcohol	2.5 - 4.0	20 - 85
	next to oxygen of an ester	4.0 - 5.0	50 - 85
	vinylic	4.5 - 6.5	110 - 150
	aromatic	6.5 - 8.0	110 - 140
	aldehyde	9.7 - 10.0	190 - 220
	alcohol	varies widely will exchange with D_2O	N/A
	carbonyl of ester, amide, or carboxylic acid (X = O, N)	N/A	165 - 185
	carbonyl of ketone or aldehyde	N/A	190 - 220

Methyl Acetate

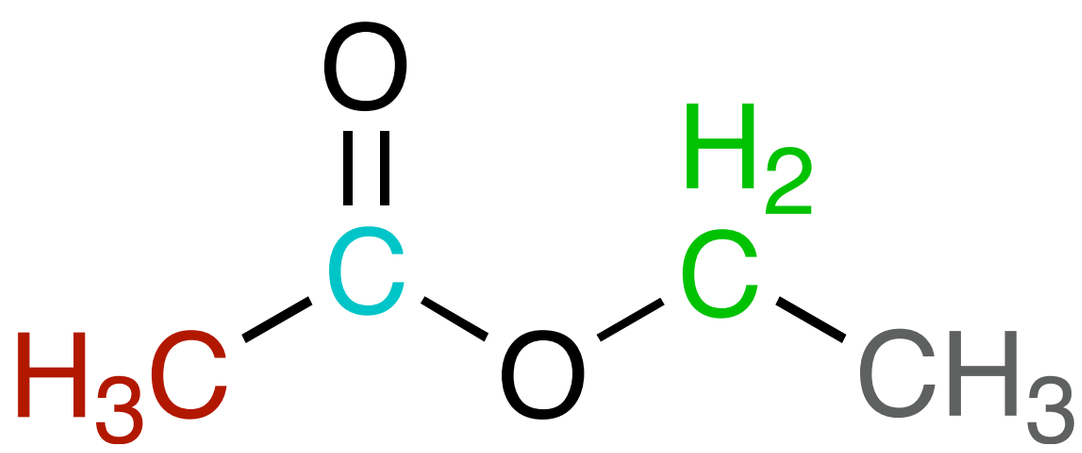


Area under peak corresponds to the number of H's for that resonance

Triphenyl Methanol

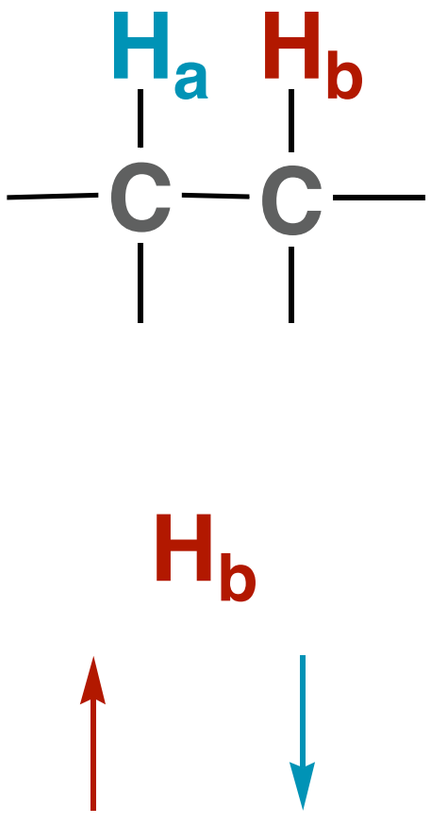


Ethyl Acetate



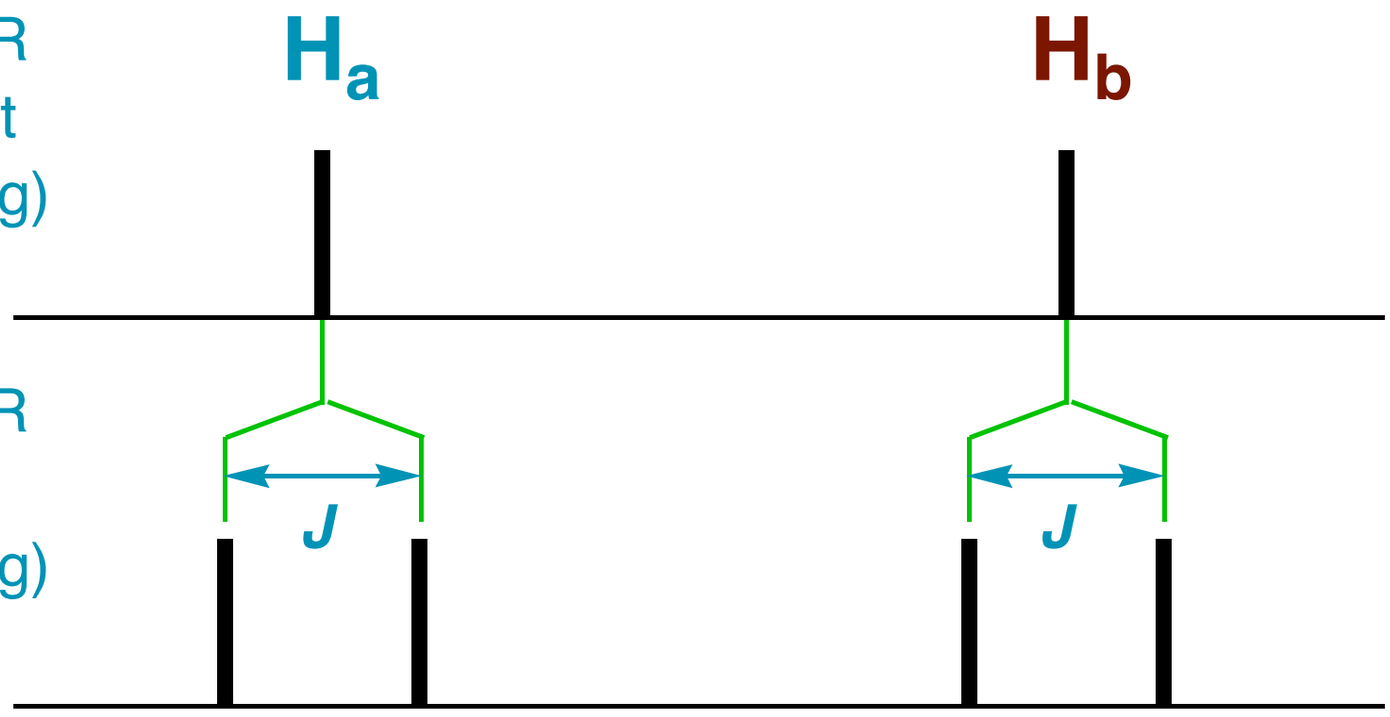
Spin Spin Splitting

- Protons on adjacent carbons also have an effect
- Resonances will split into n+1 number of peaks



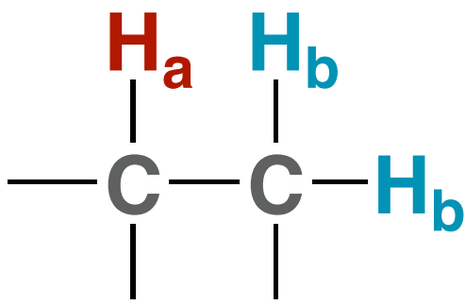
^{1}H NMR (without coupling)

^{1}H NMR (with coupling)

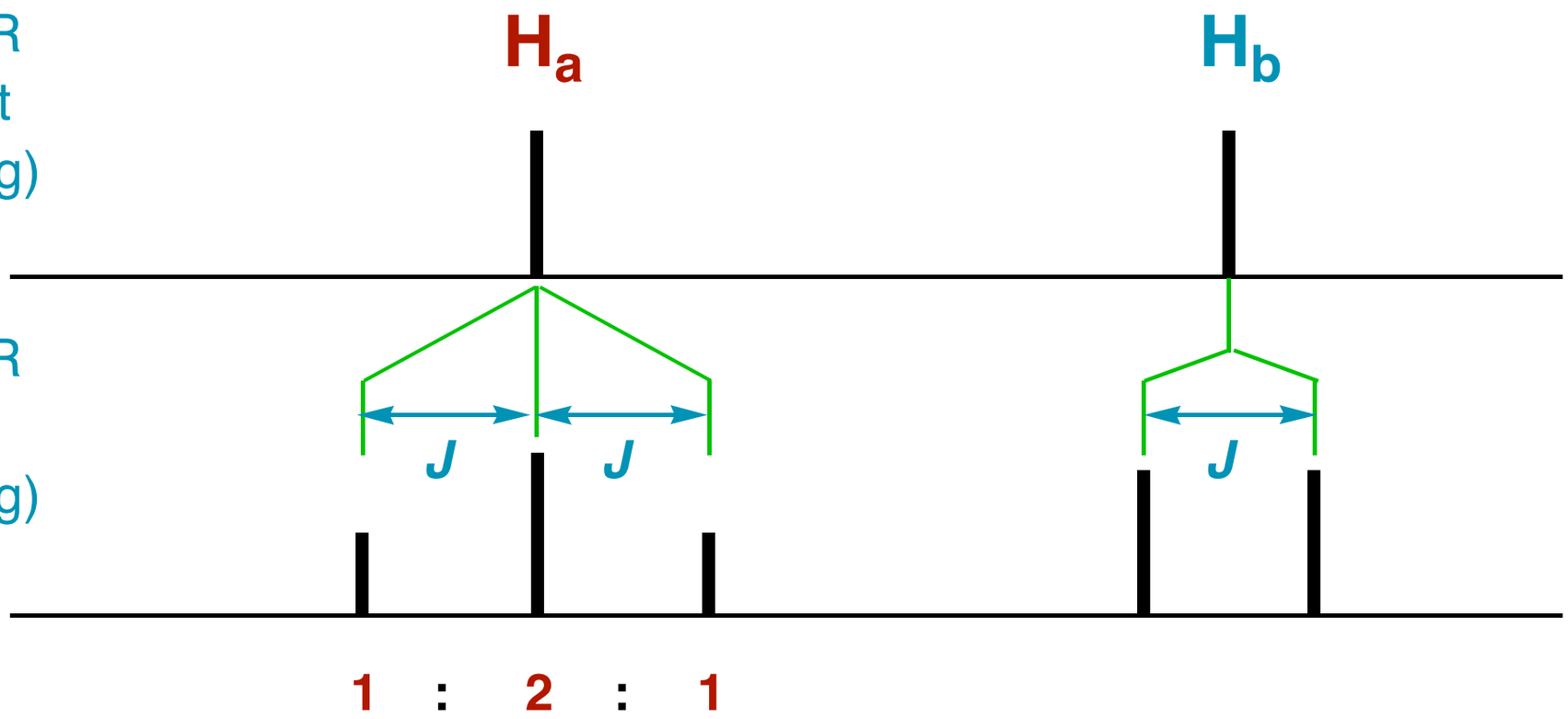


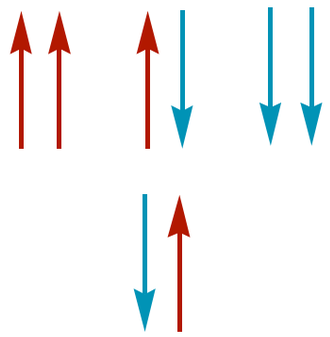
Spin Spin Splitting

- Two hydrogens split neighbors into a triplet



^{1}H NMR (without coupling)

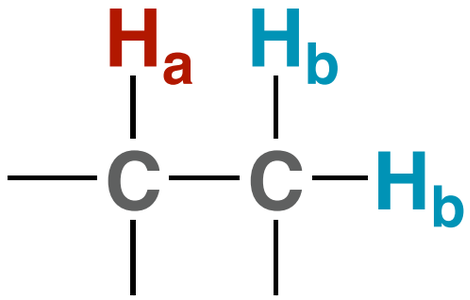




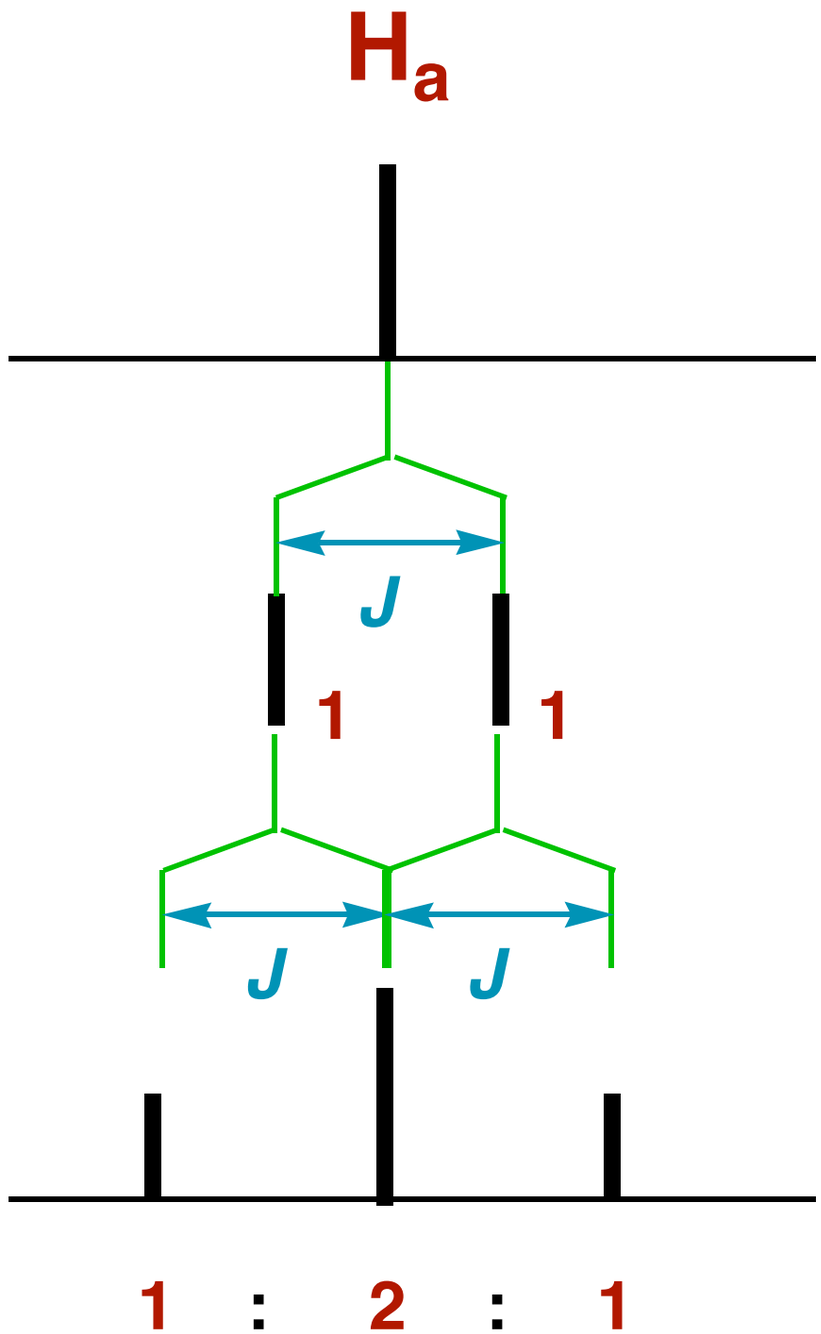
^{1}H NMR (with coupling)

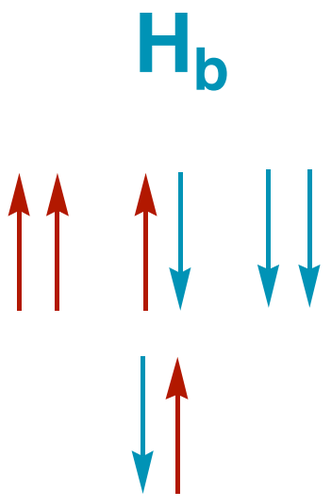
Spin Spin Splitting

- Every splitting can be broken down into a series of doublets



^{1}H NMR (without coupling)

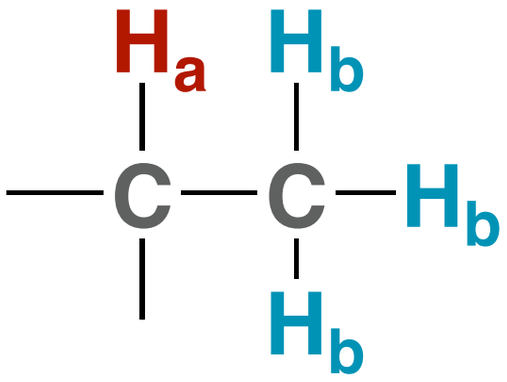


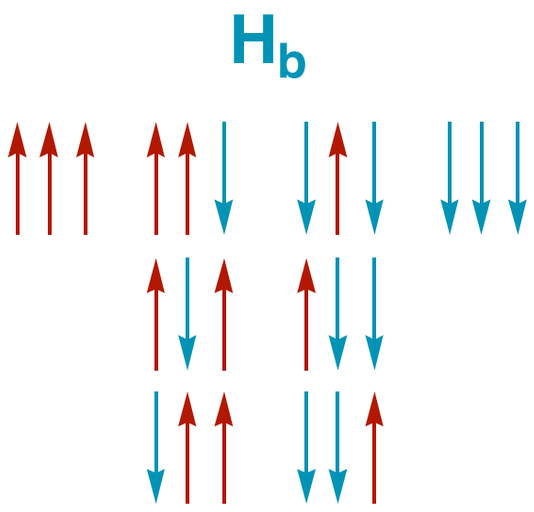


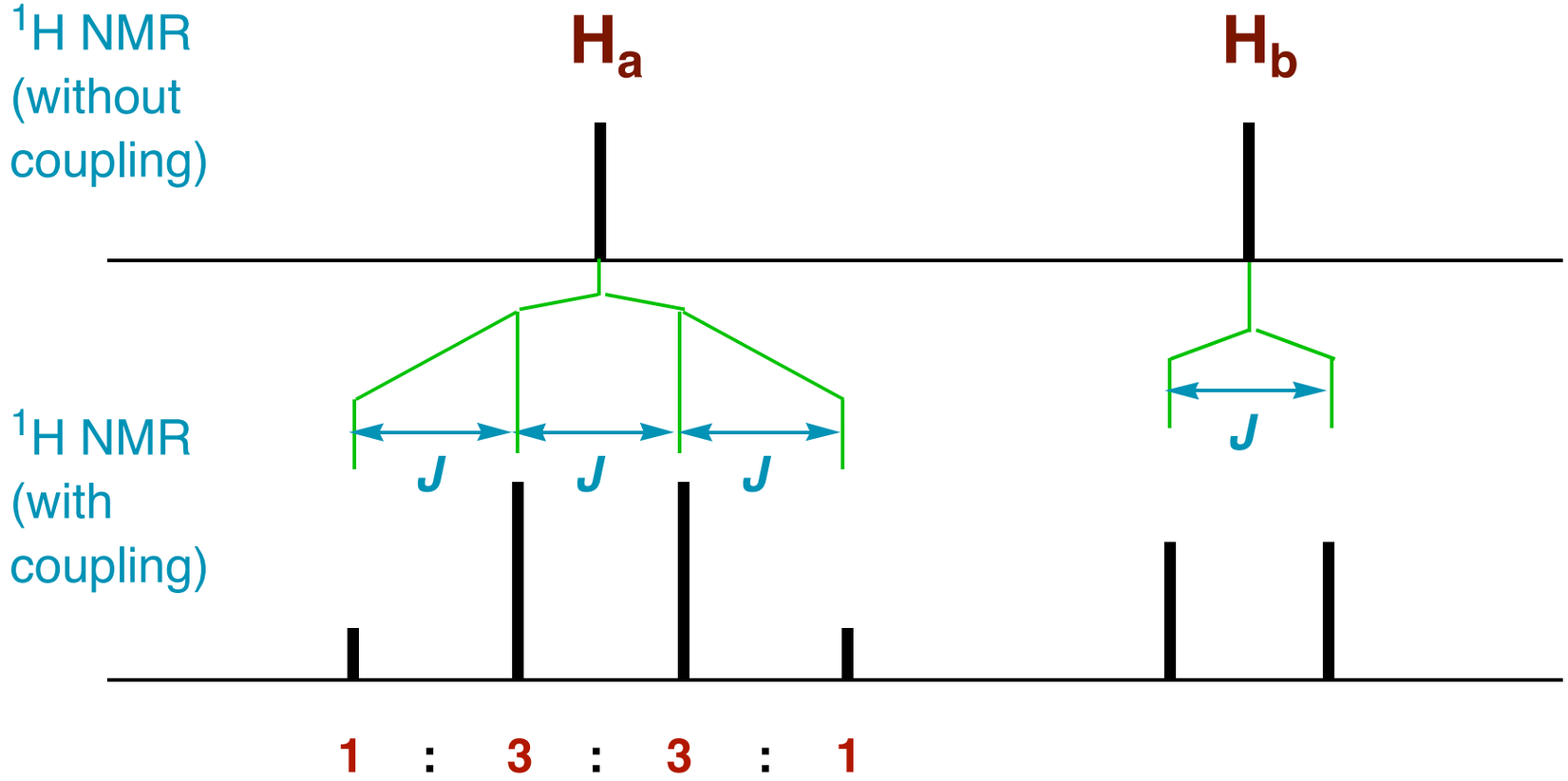
^{1}H NMR (with coupling)

Spin Spin Splitting

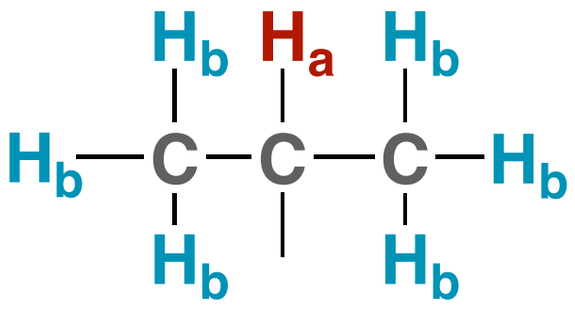
- Three neighbors - Quartet







Higher Spin Spin Splitting



H_a will split into 7 peaks

64 different combinations of 6 spins

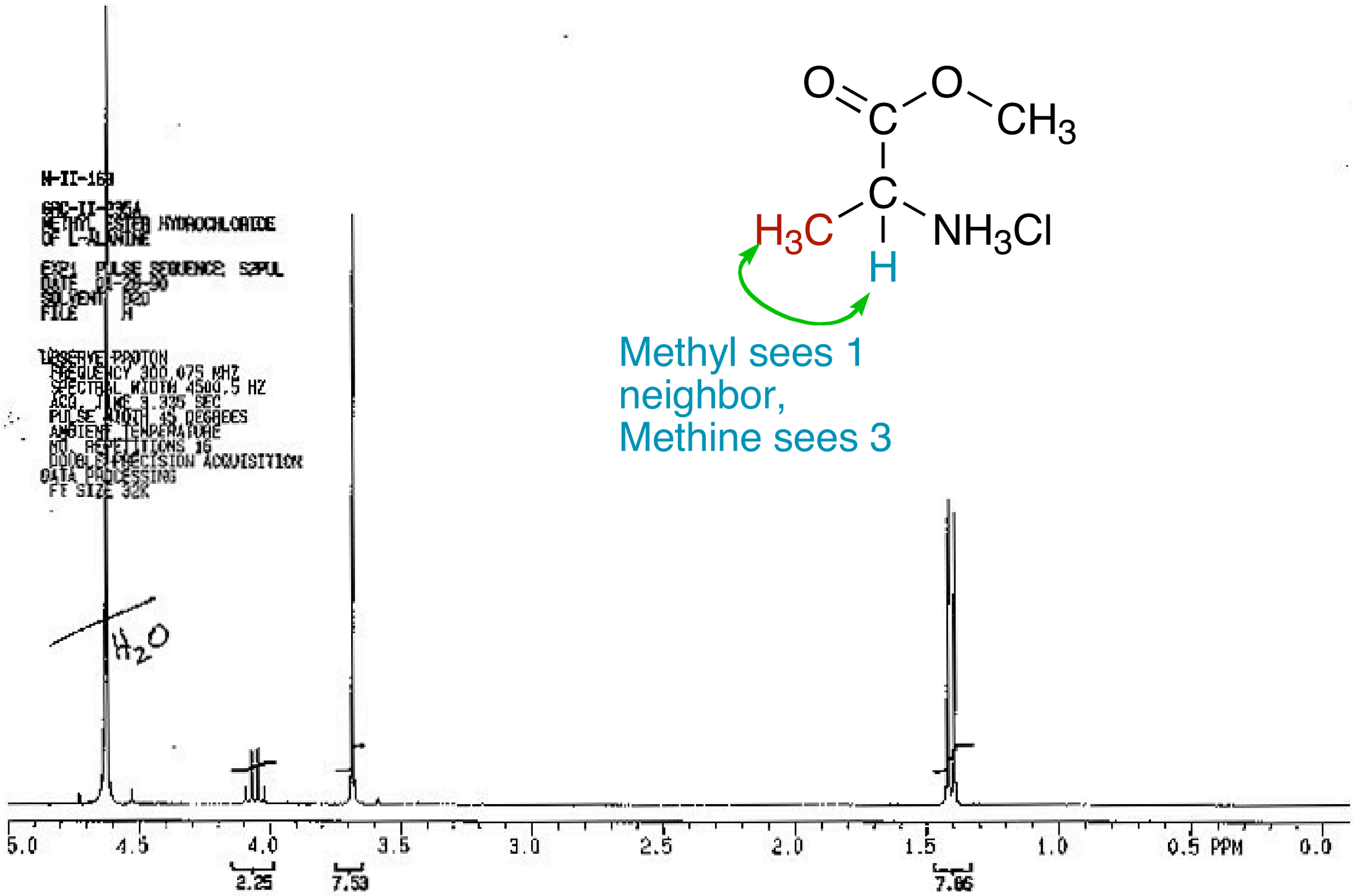
Pascal's Triangle

singlet			1				
doublet		1		1			
triplet		1		2		1	
quartet	1		3		3		1
quintet		1		4		6		4		1
sextet			1		5		10		10		5		1
septet		1		6		15		20		15		6		1

Summary of Spin Spin Splitting

- Proton resonance split into n+1 number of peaks
- Relative ratio of peaks depends on number of spin states of the neighbors.
- Adjacent protons will couple with the same coupling constant.
- Protons farther away usually do not couple.
- Chemically equivalent protons cannot couple (eg. $ClCH_2CH_2Cl$).

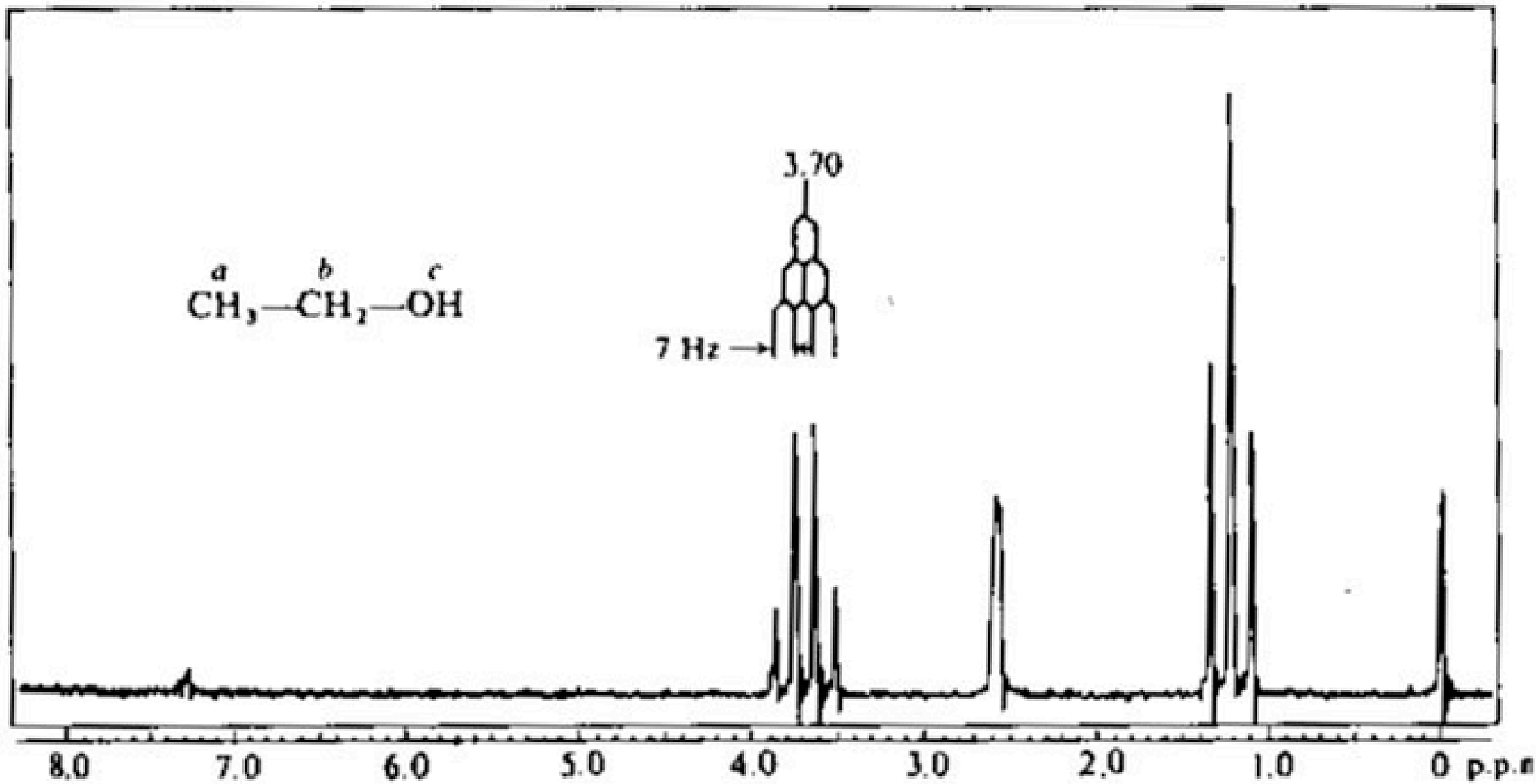
Doublet Splitting



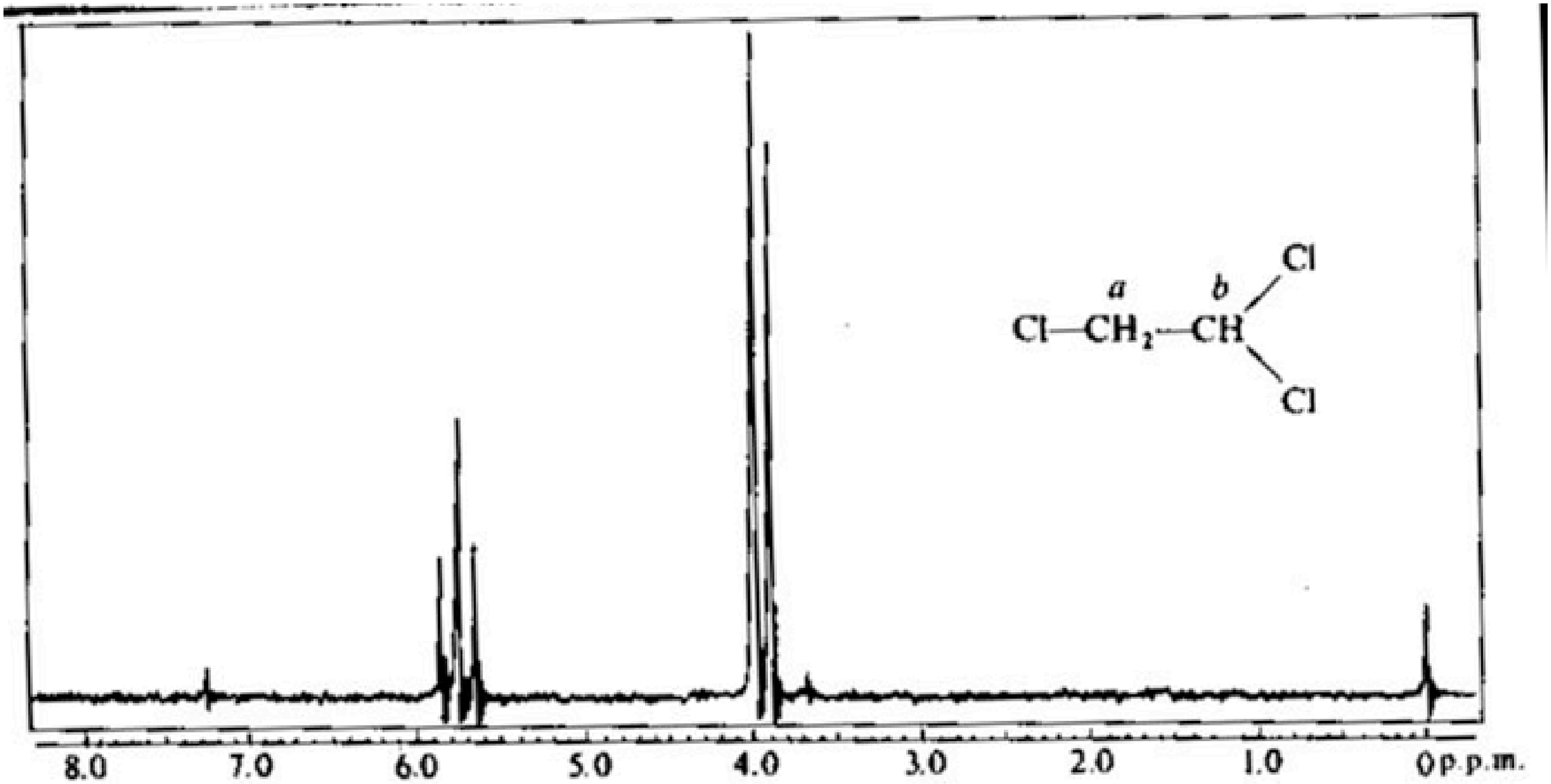
Methyl sees 1 neighbor,
Methine sees 3

Ethanol

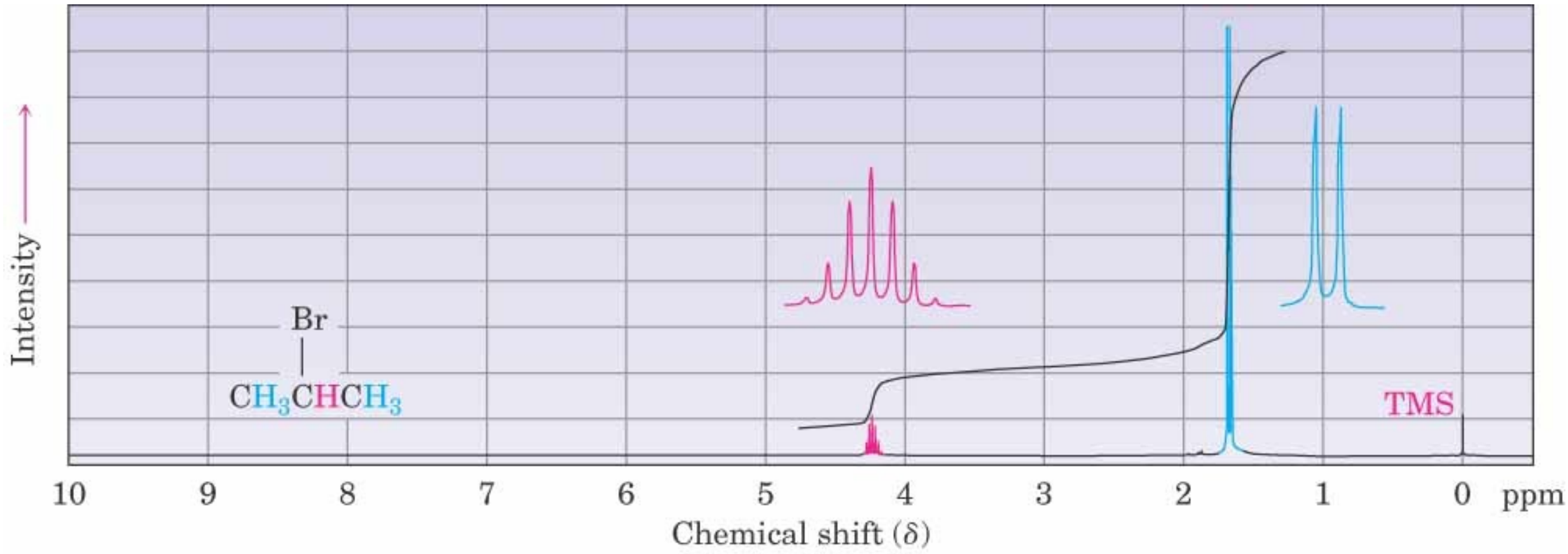
- Note that the OH (and NH) usually don't couple.



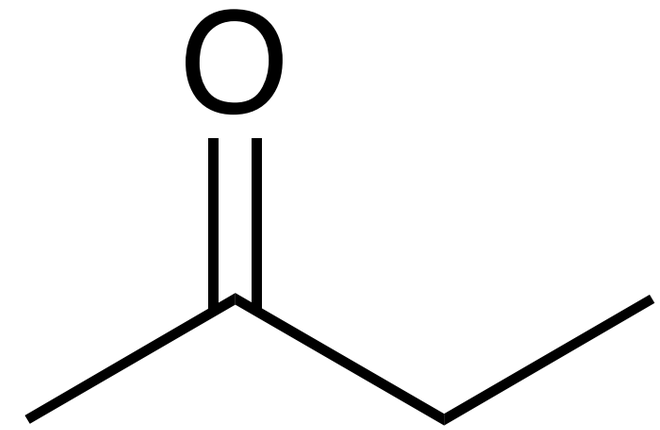
1,1,2-Trichloroethane



2-Bromopropane

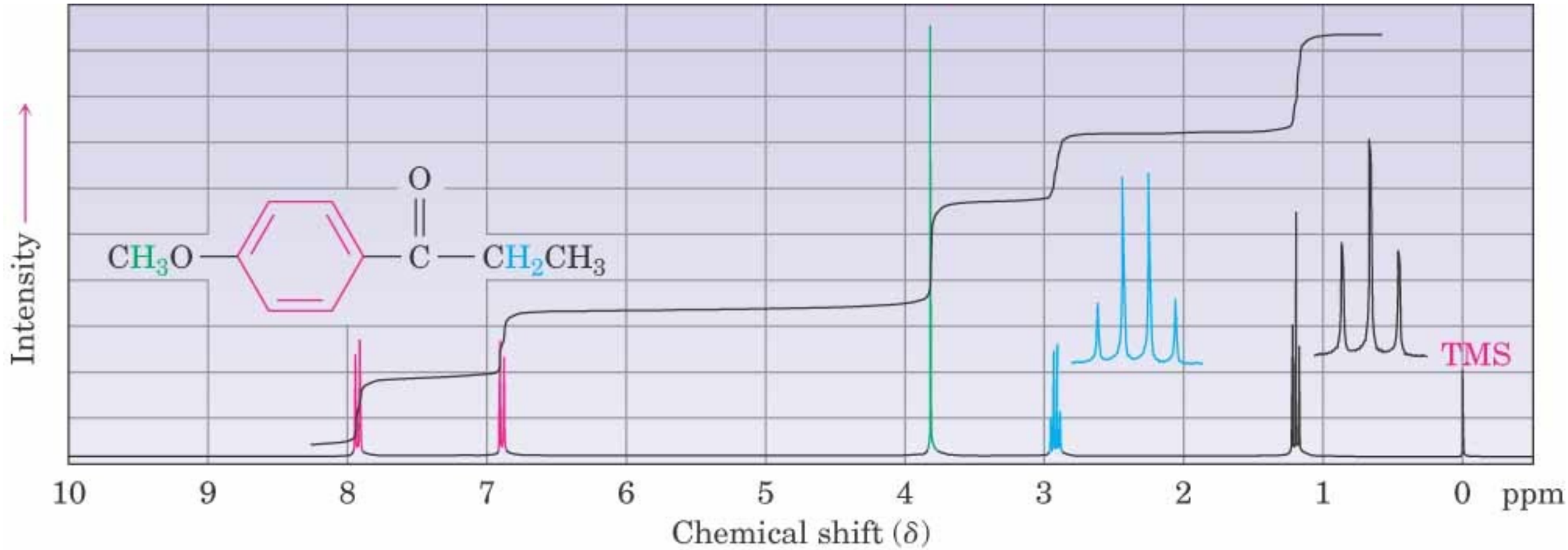


Butanone


O

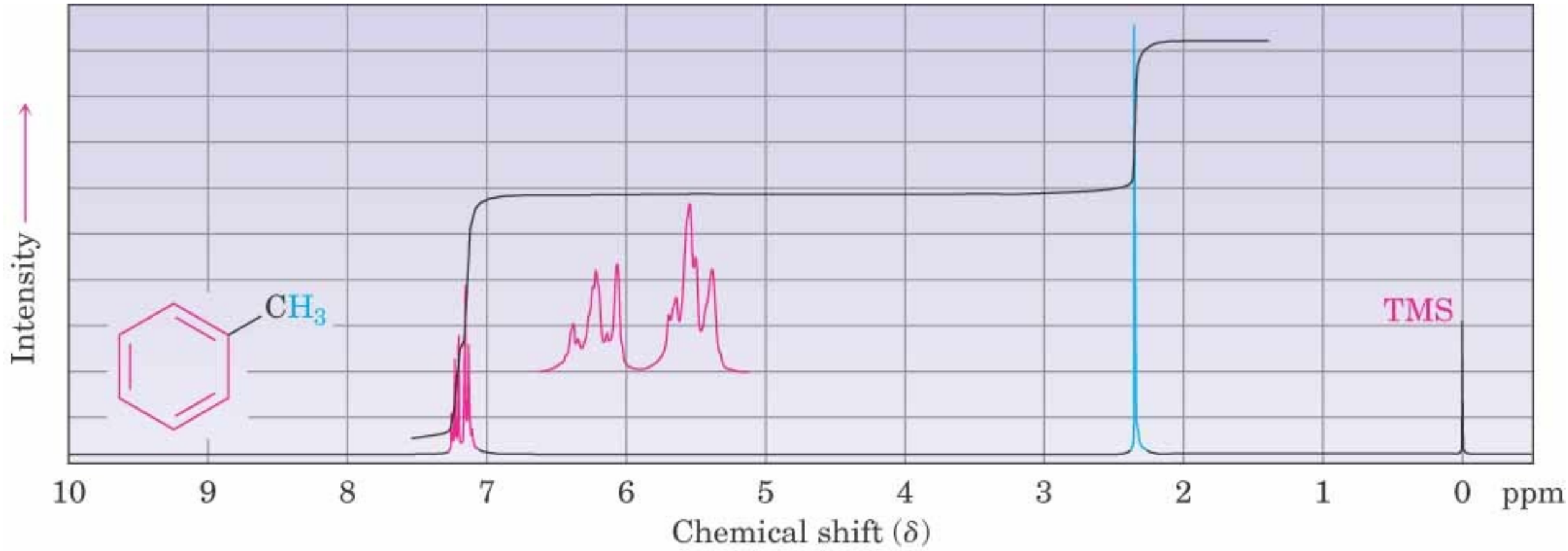
642.78
314.74
322.05
307.44
743.99
736.69
751.29
729.39
-0.00
3.0
2.5
2.0
1.5
1.0
0.5
-0.0
ppm
1.95
3.03
3.00
0.26

para-Methoxypropiophenone



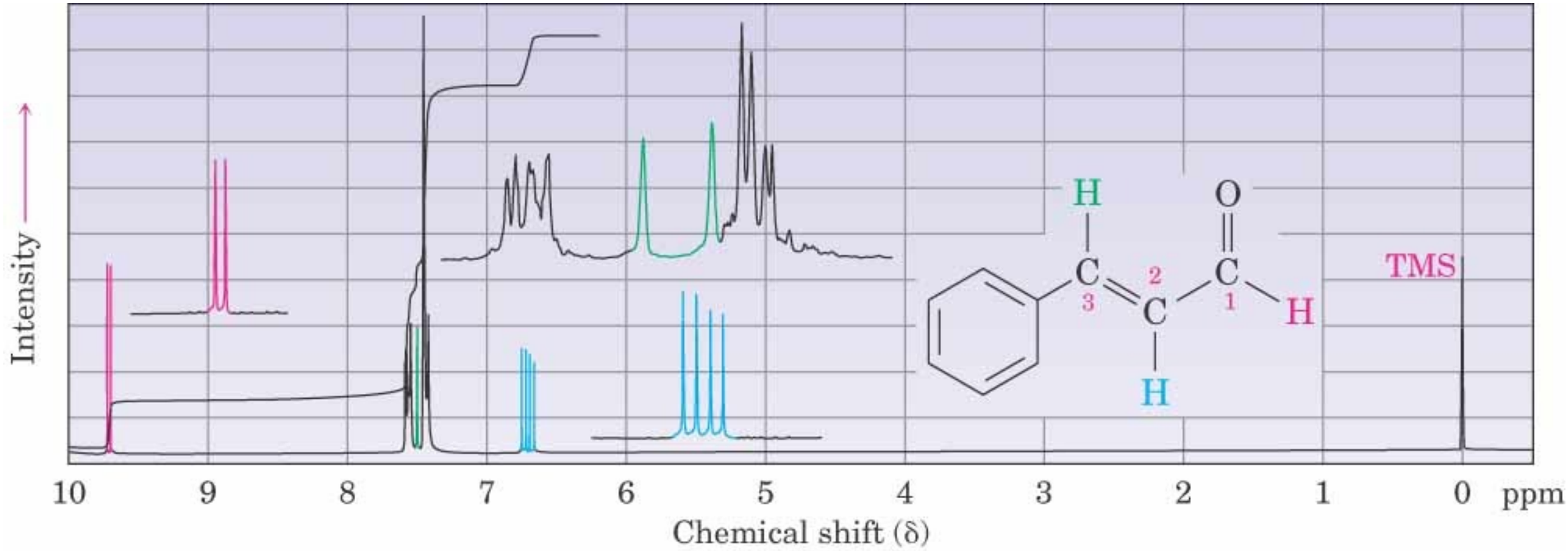
Toluene

- Sometimes peaks overlap



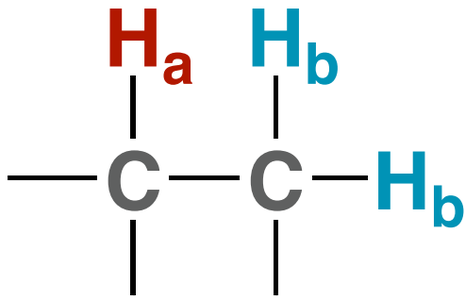
Cinnamaldehyde

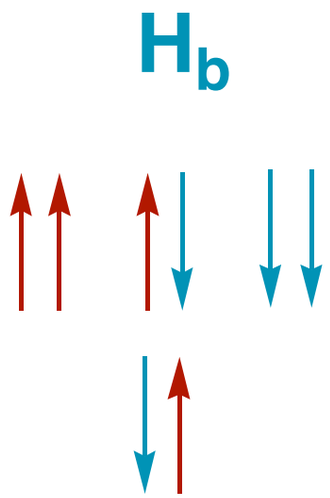
- Multiple Coupling



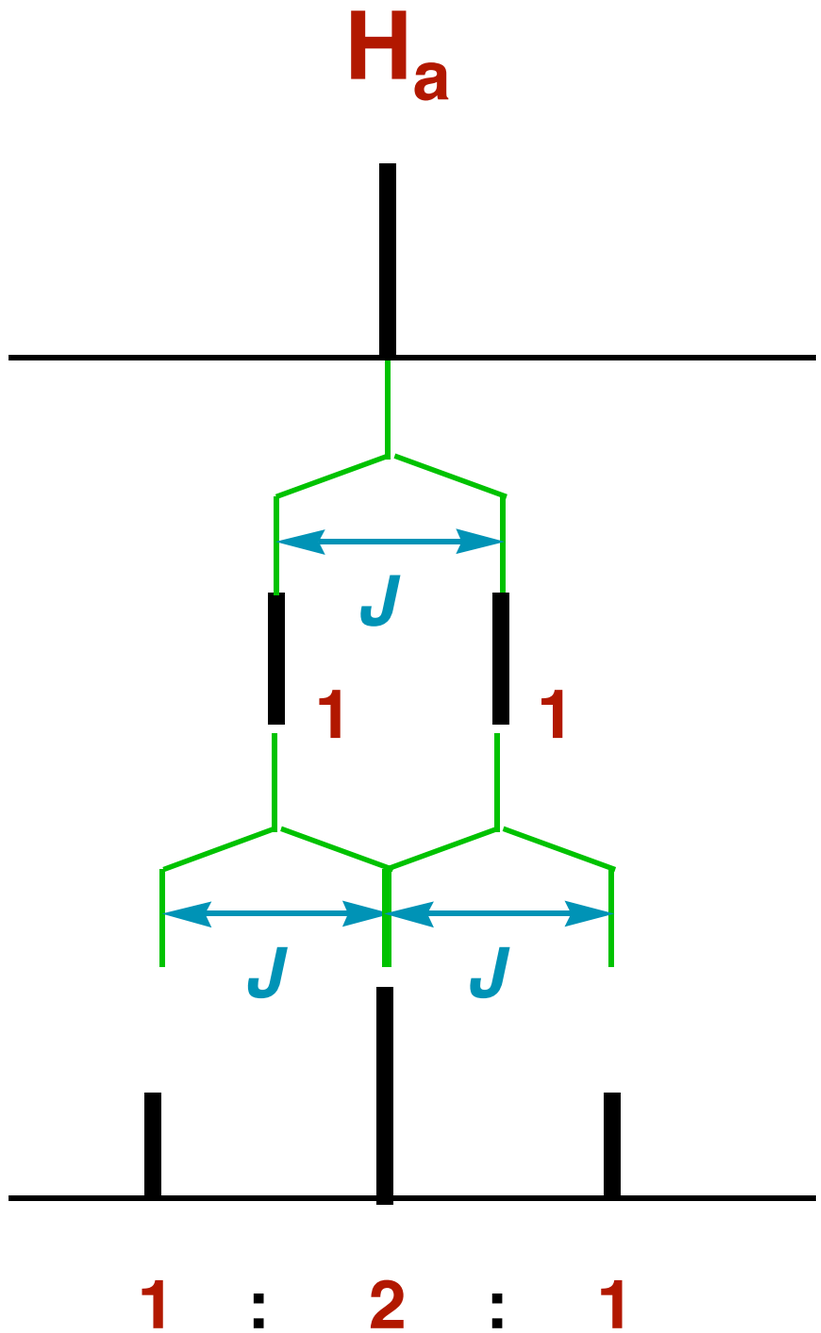
Spin Spin Splitting

- Every splitting can be broken down into a series of doublets





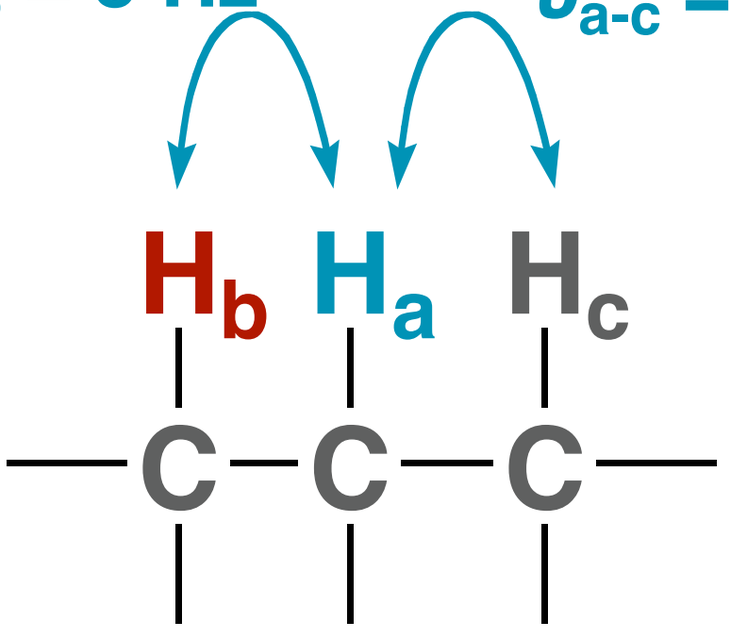
^{1}H NMR (without coupling)



^{1}H NMR (with coupling)

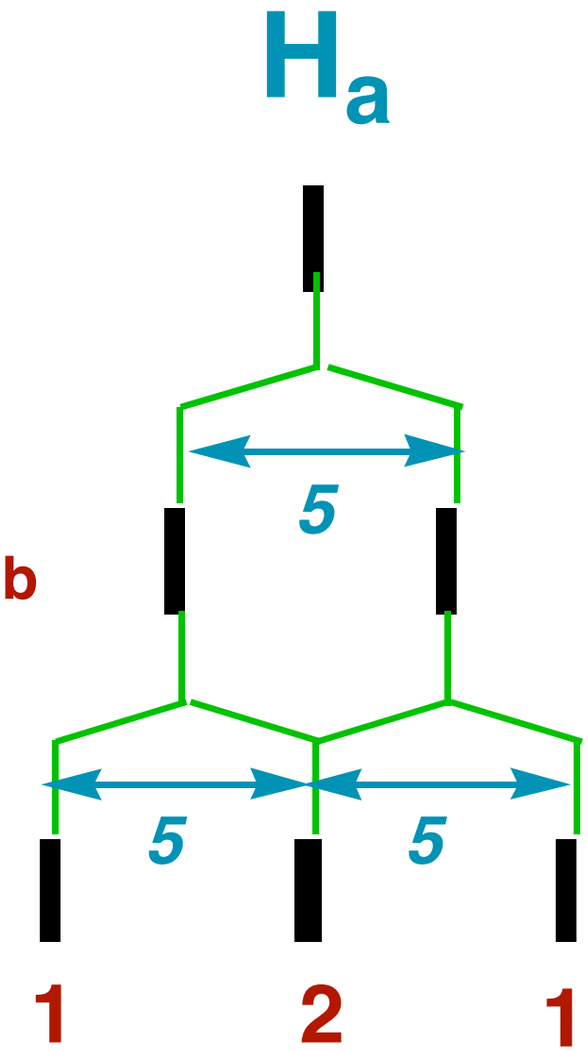
Coupling with the same *J*

$J_{a\text{-}b}$ = 5 Hz $J_{a\text{-}c}$ = 5 Hz

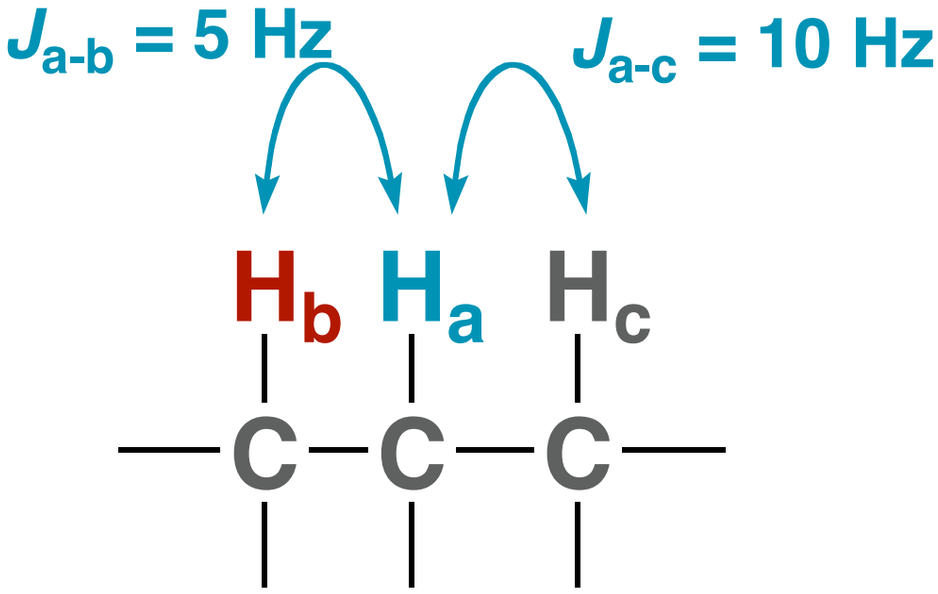


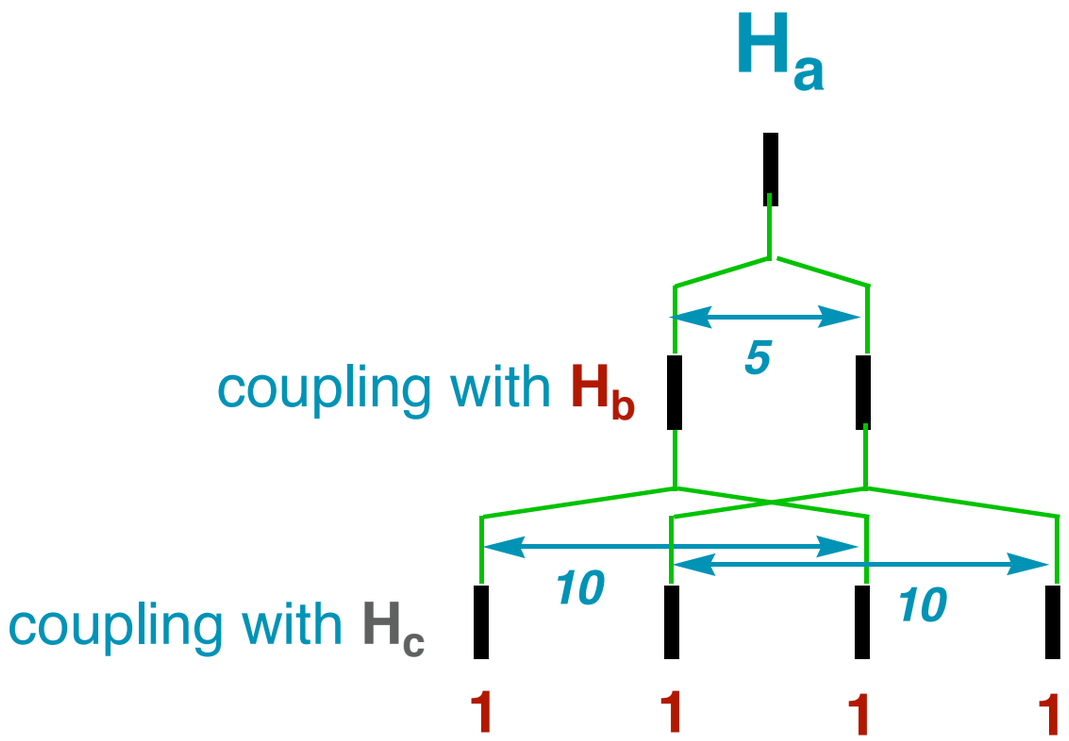
coupling with H_b

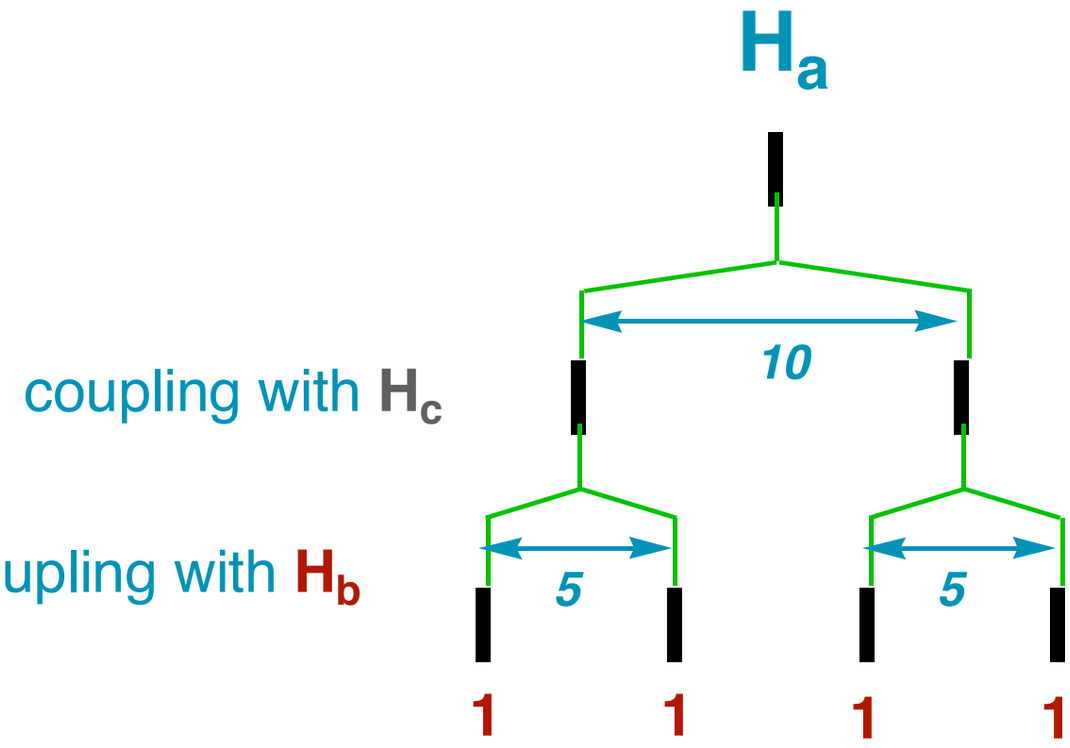
coupling with H_c



Coupling with different *J* values

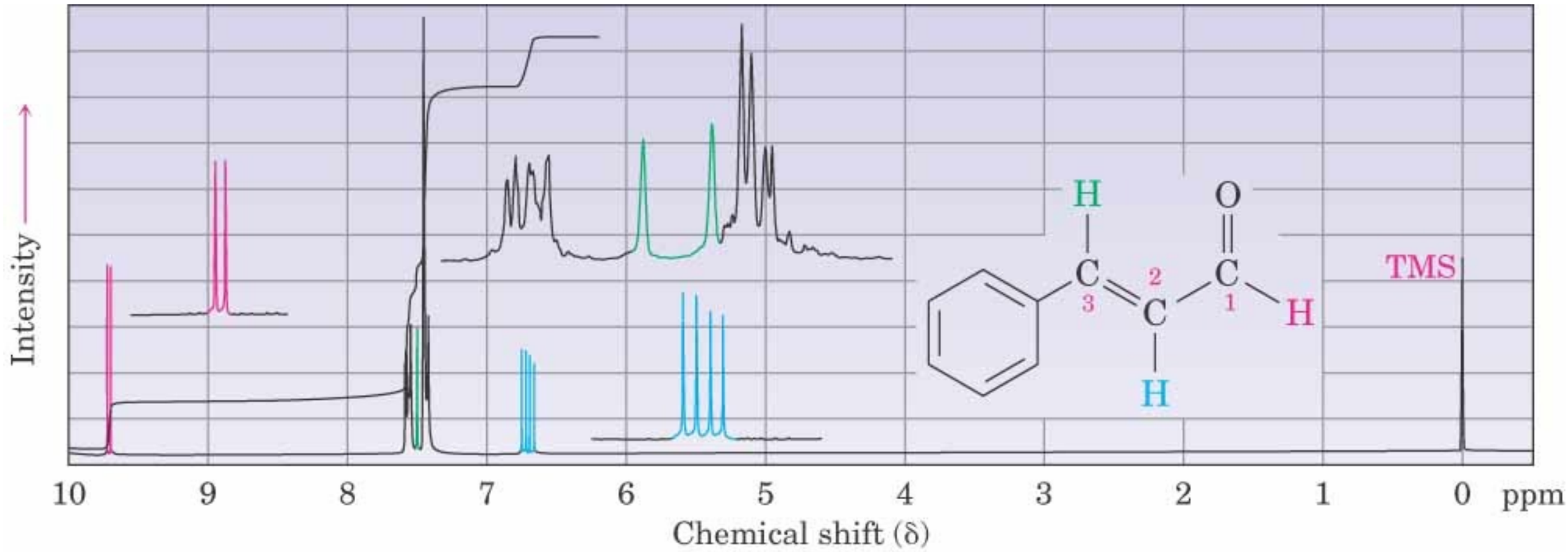




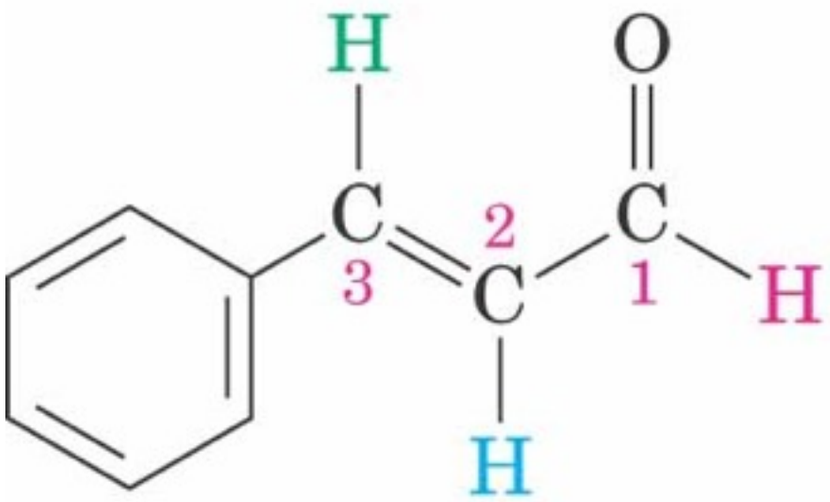


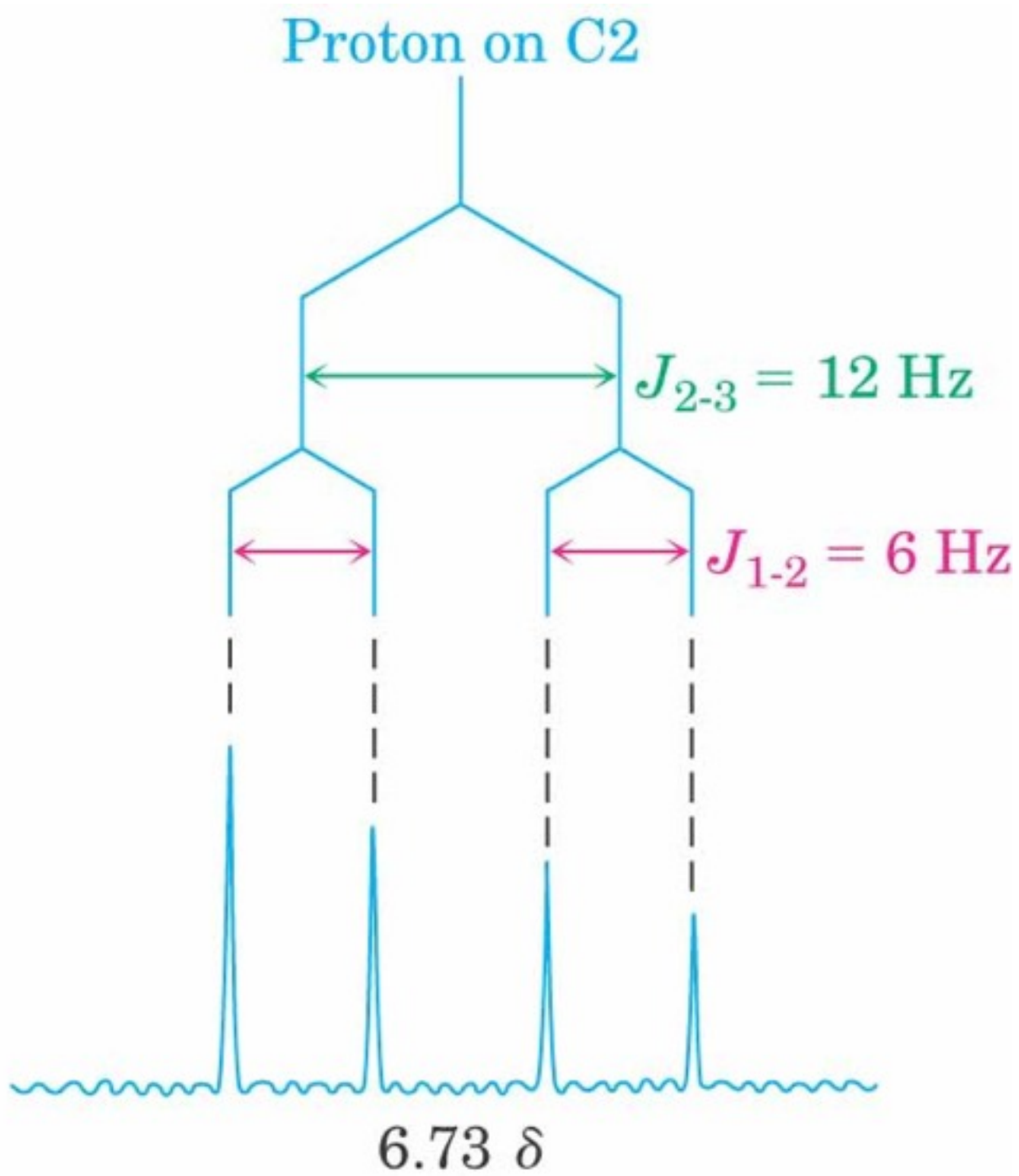
Cinnamaldehyde

- Multiple Coupling
- *J* H1-H2 = 6 Hz, H2-H3 = 12 Hz

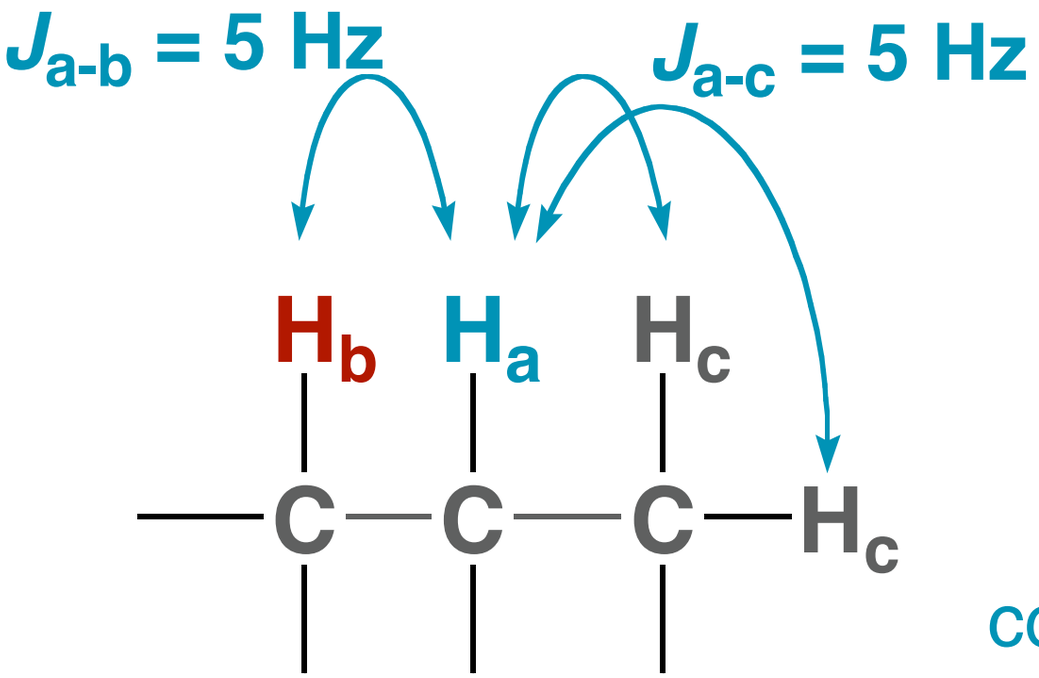


Cinnemaldehyde





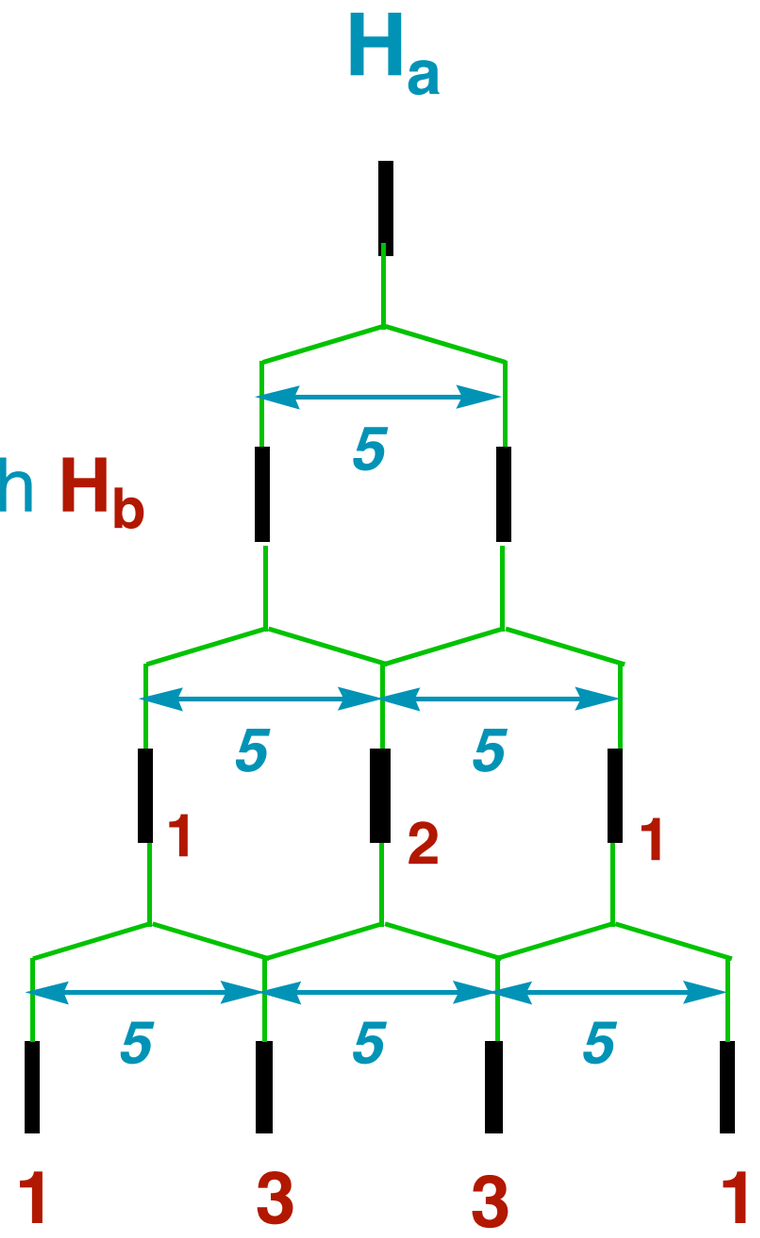
Multiple Coupling - Identical *J*



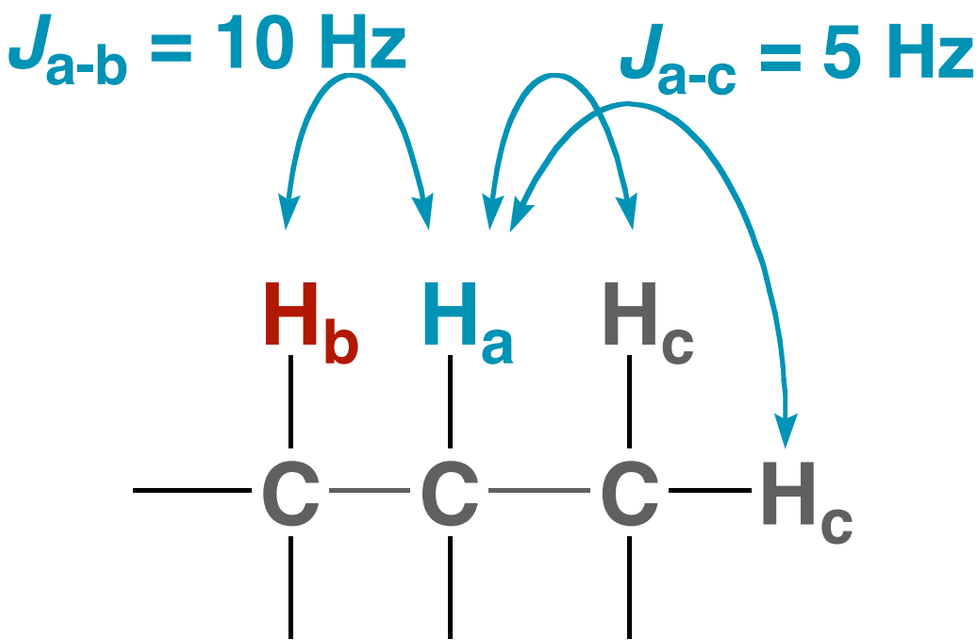
coupling with H_b

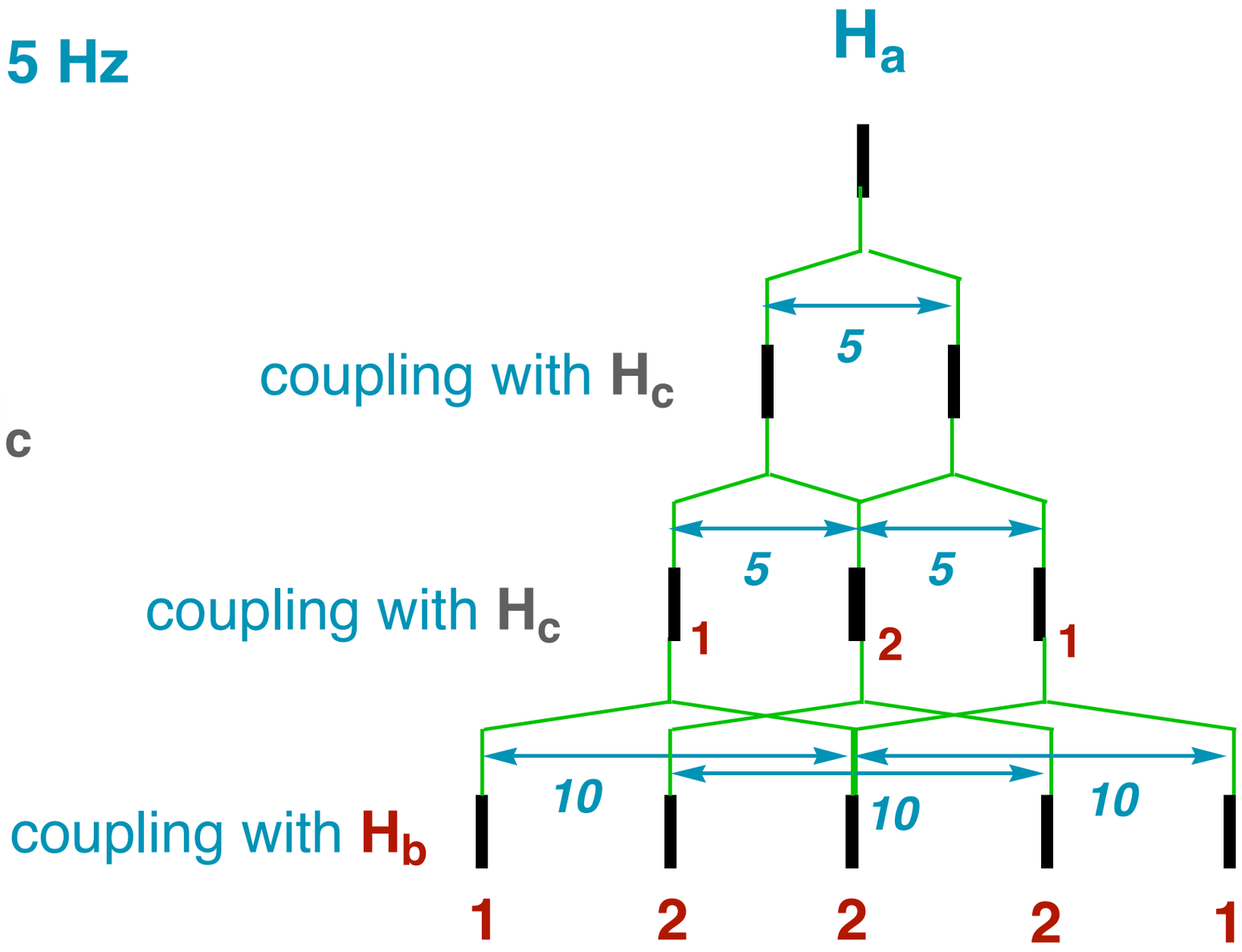
coupling with H_c

coupling with H_c

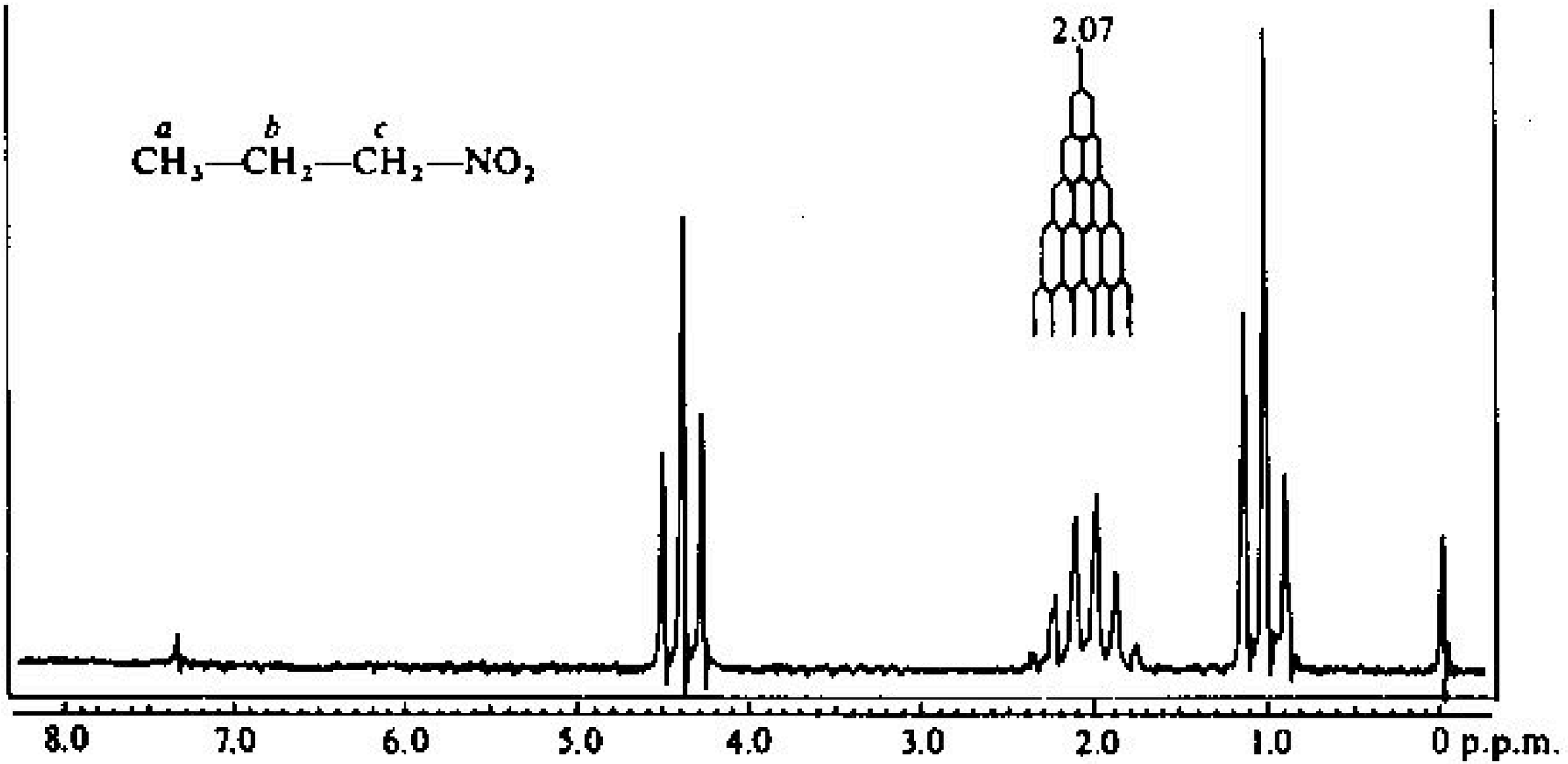


Multiple Coupling - Different *J*





Nitropropane



Strategies for Determining Unknows

- Given the Molecular Formula - calculate degrees of unsaturation.
- Identify functional groups
- Identify pieces of the structure
- Put the pieces together in a reasonable way
- Double check that your structure matches all the data given.