344 | Organic Chemistry Laboratory

Introduction to ^{1}H-NMR Spectroscopy Part I

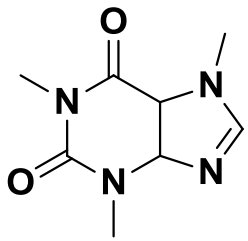
Main topics

- Equivalent/non-equivalent protons

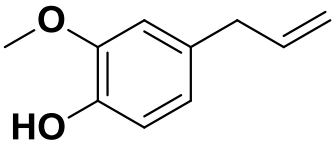
- Interpreting simple ^{1}H-NMR spectra

- Spin-spin coupling, n+1 rule

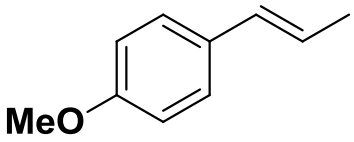
How do we know the structure of these molecules?



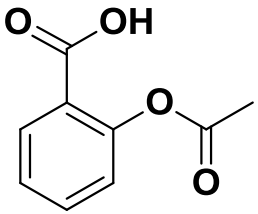
Caffeine



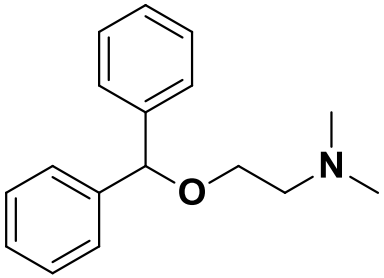
Eugenol



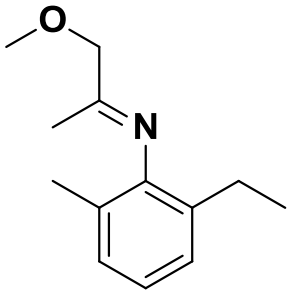
Anethole



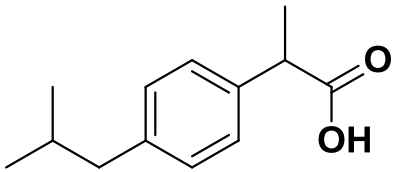
Aspirin



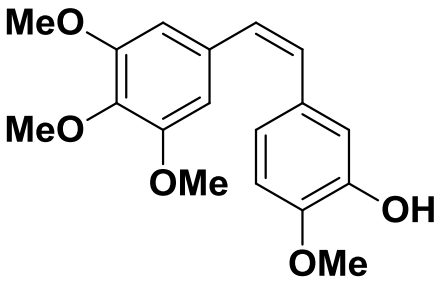
Diphenhydramine



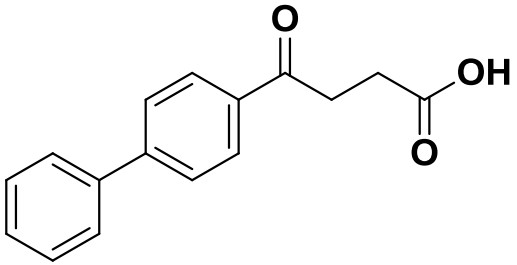
Herbicide precursor



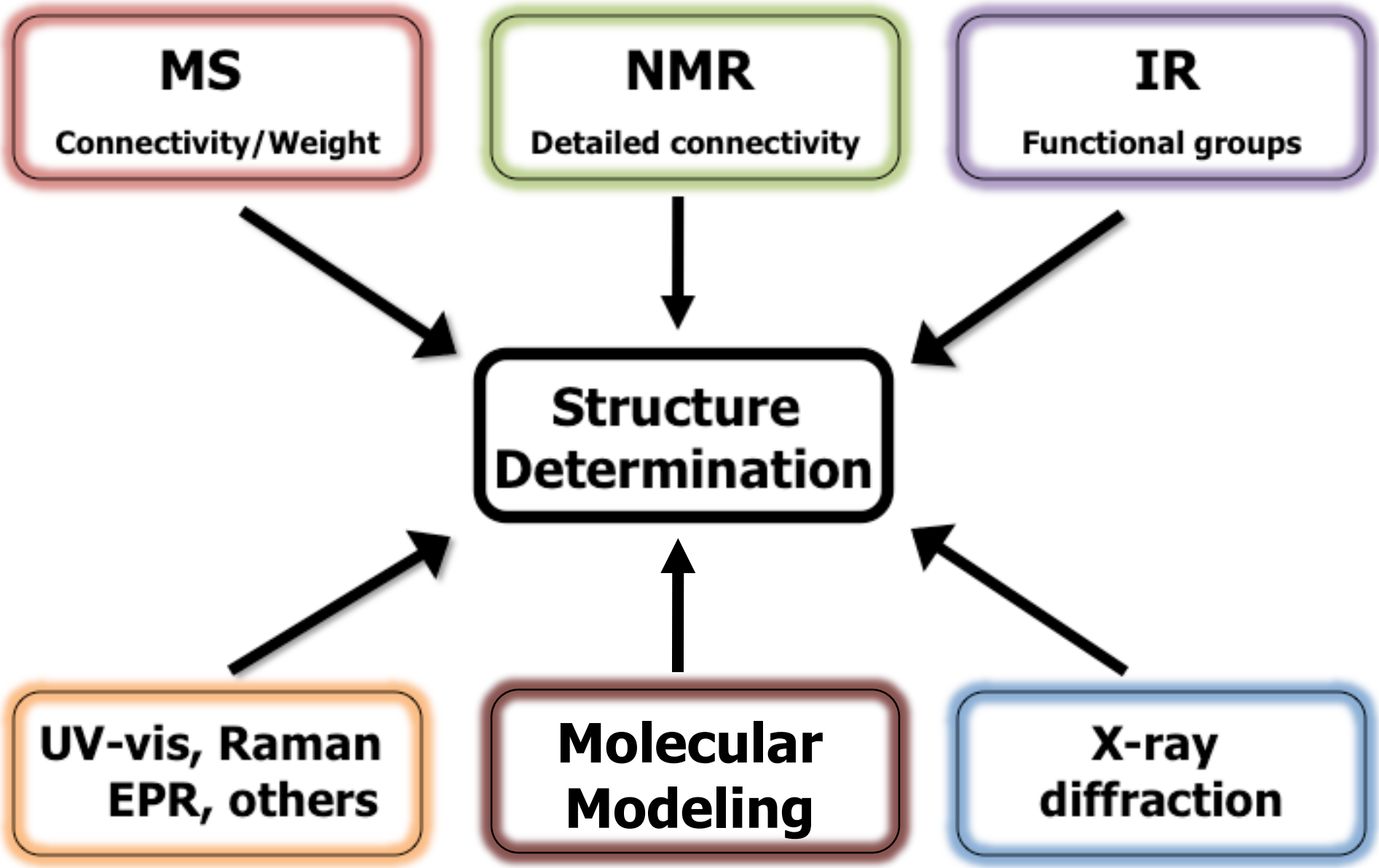
Ibuprofen



Combretastatin A-4

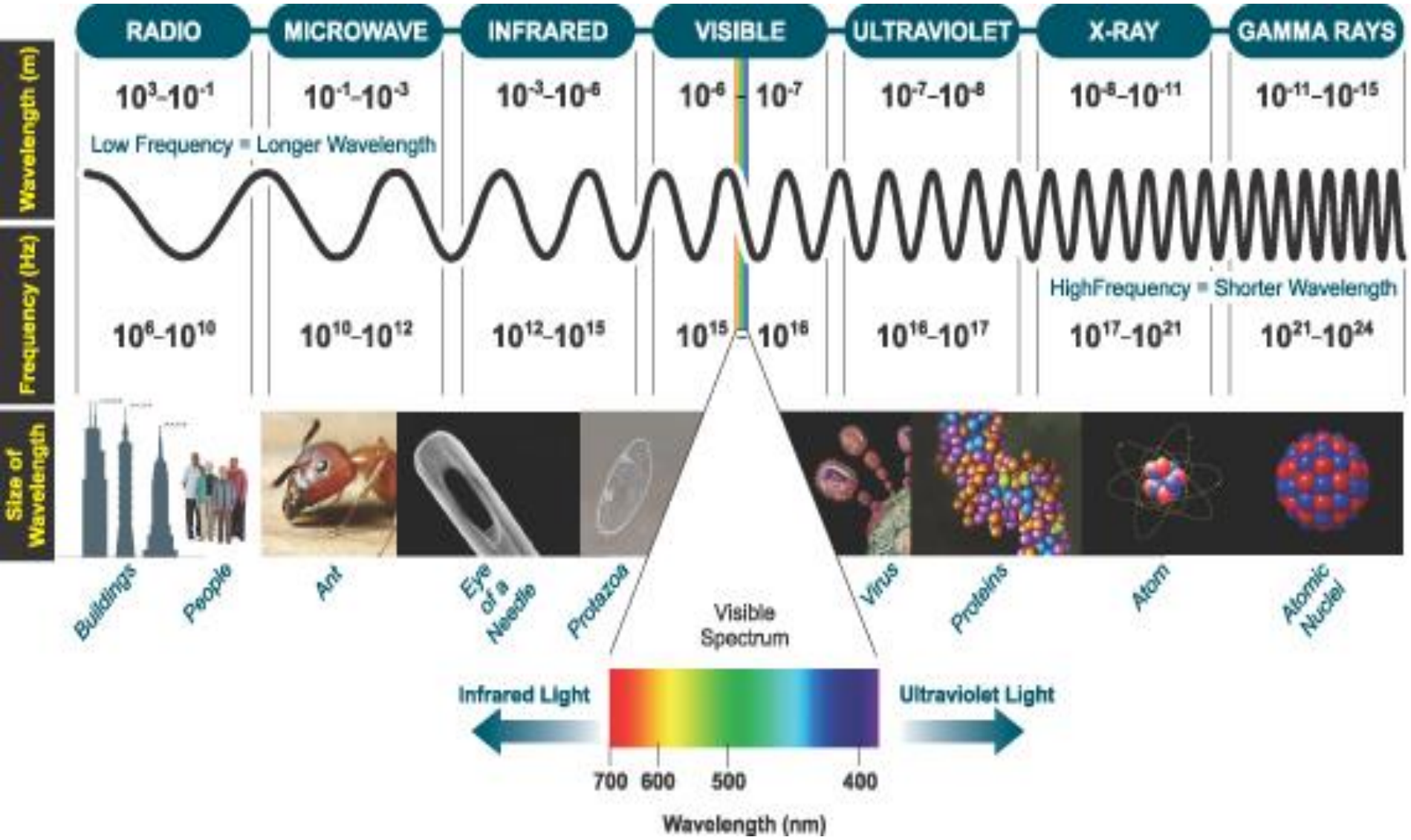


Fenbufen (NSAID)


MS
Connectivity/Weight
NMR
Detailed connectivity
IR
Functional groups
Structure Determination
UV-vis, Raman EPR, others
Molecular Modeling
X-ray diffraction

E = hν E = energy (kJ/mol)

ν = frequency (Hz), h = Planck constant



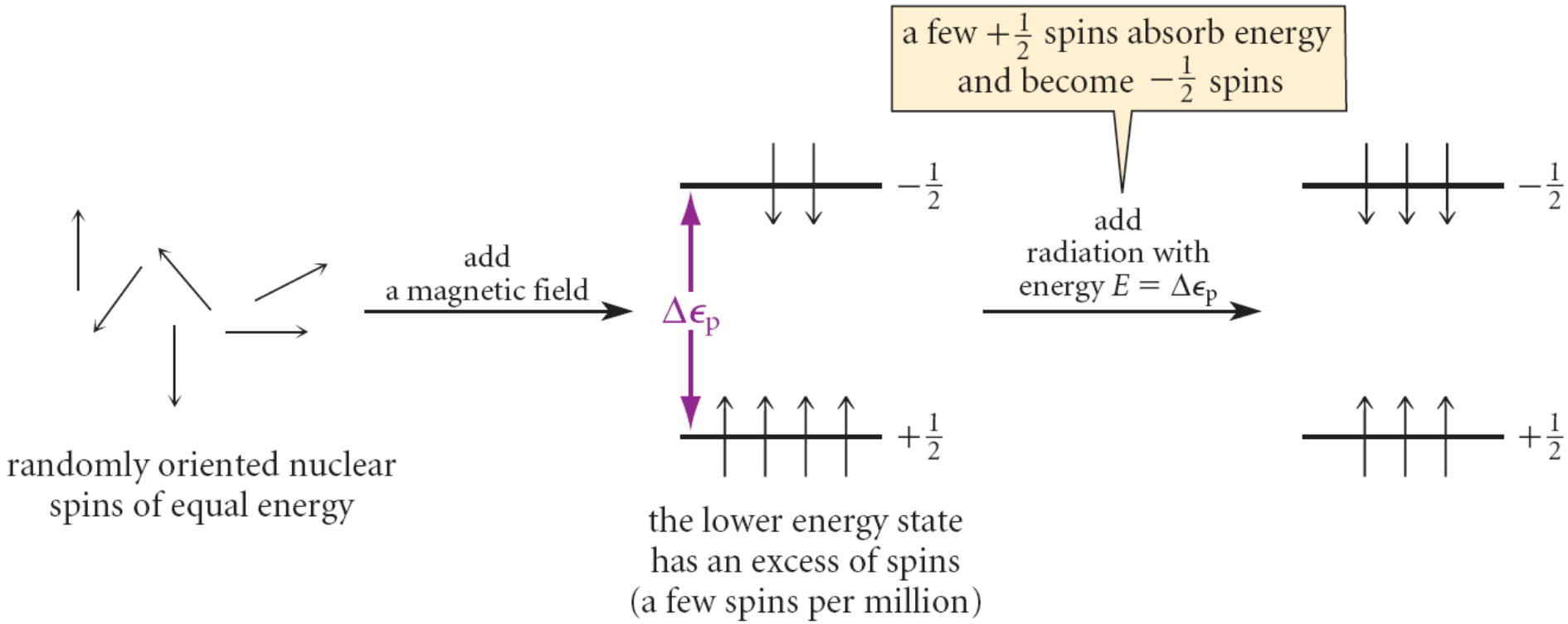
Background & theory: pp. 536-538 "Organic Chemistry" 5th. Ed. Loudon.

Nuclear Magnetic Resonance (NMR)

Spin ½ nuclei ^{1}H, ^{13}C, ^{19}F, ^{29}Si, ^{31}P

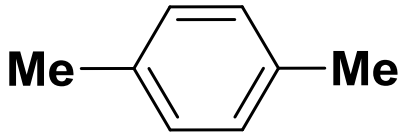
NMR active, easy to do, widely used

Nuclei behave like a bar magnet



Background & theory: pp. 578-636 "Organic Chemistry" 5th. Ed. Loudon.

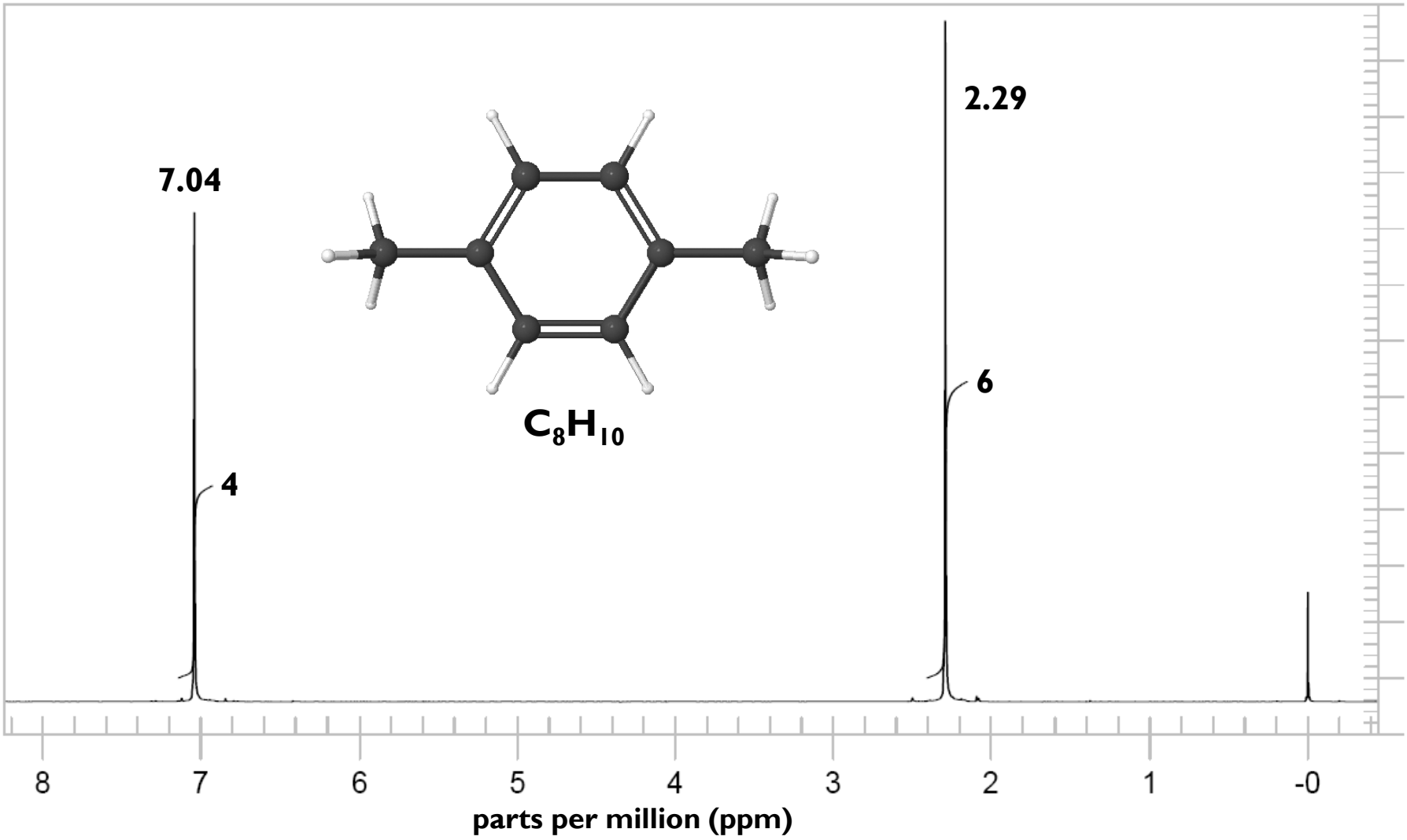
The ^{1}H-NMR spectrum



1,4-Dimethylbenzene

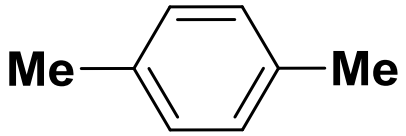
(*para*-Xylene)

300 MHz ^{1}H NMR
In CDCl3



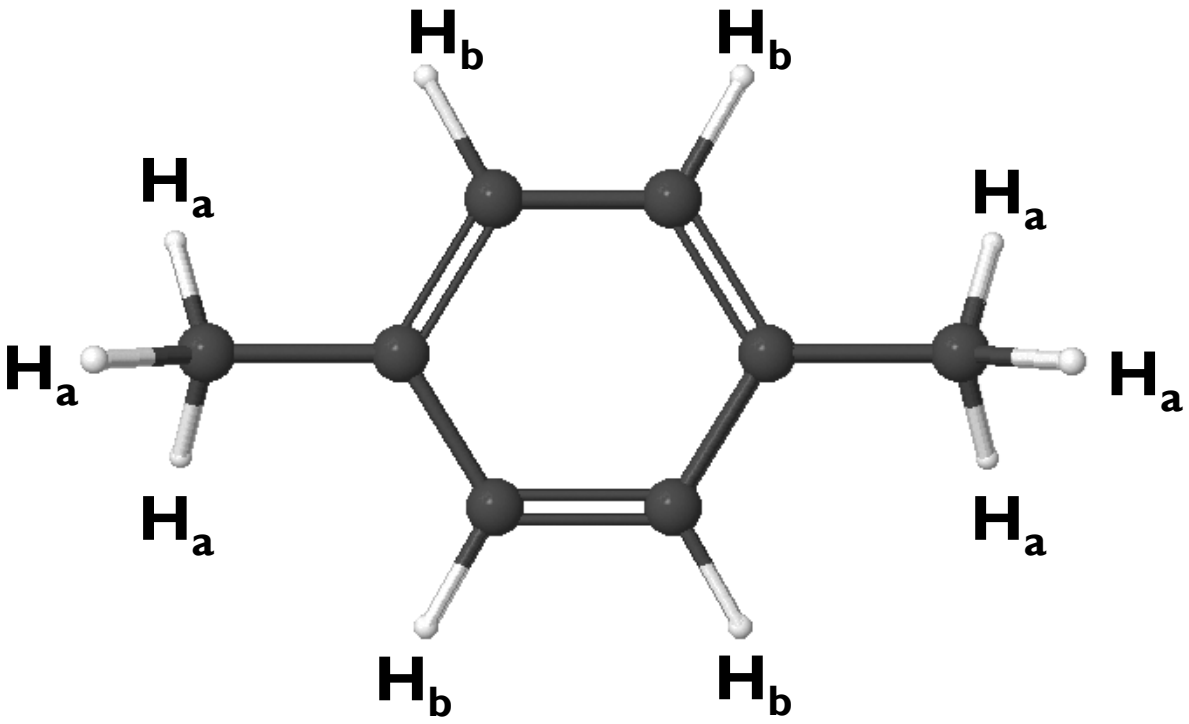
C_8H_{10}

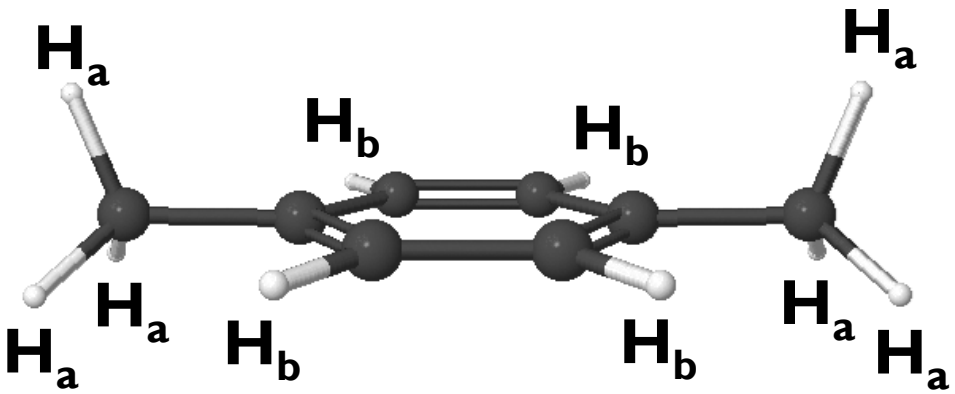
Analyzing *para*-Xylene



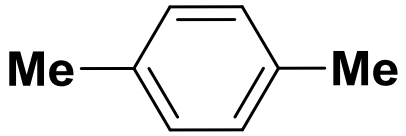
***para*-Xylene**

C_8H_{10}





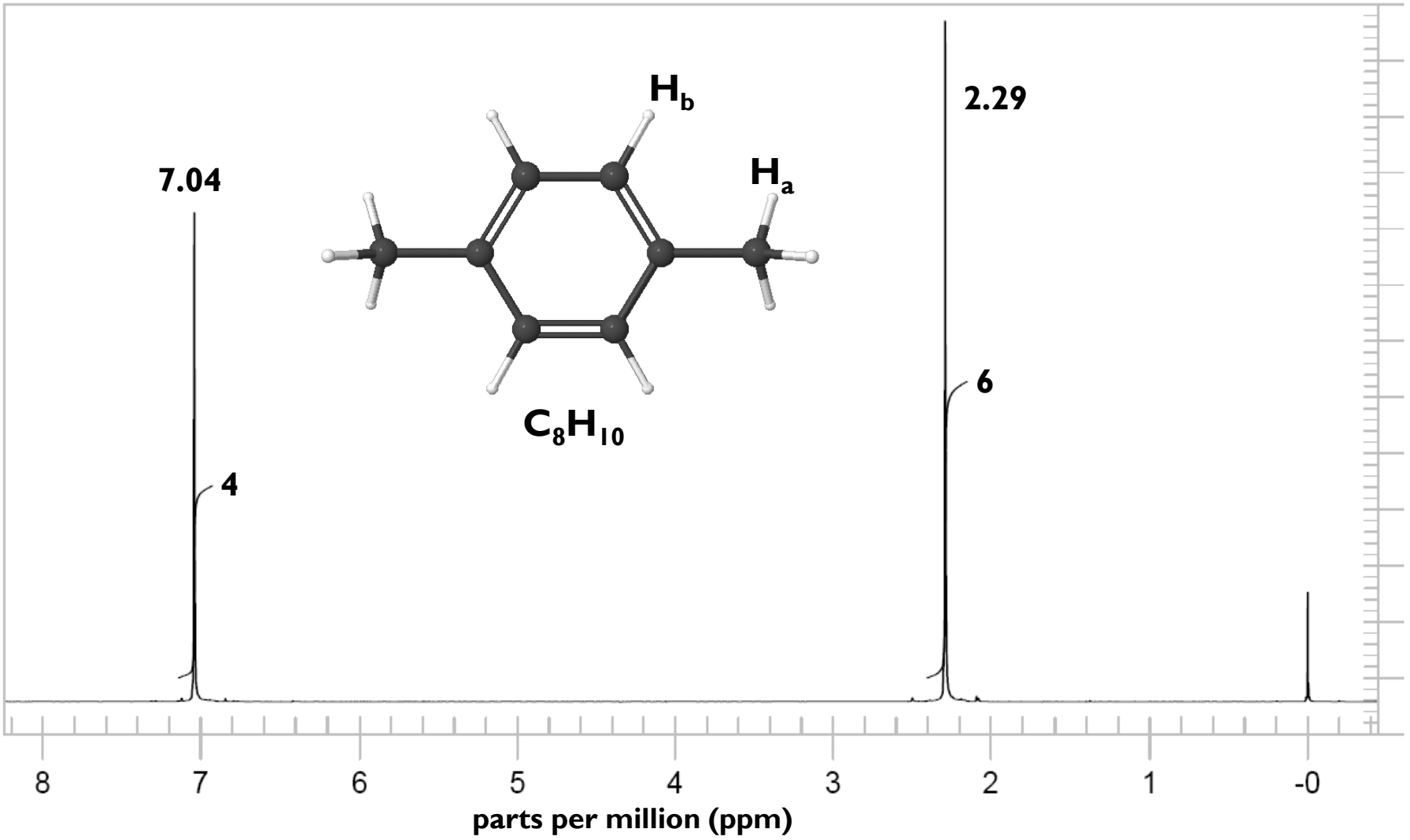
The ^{1}H-NMR spectrum

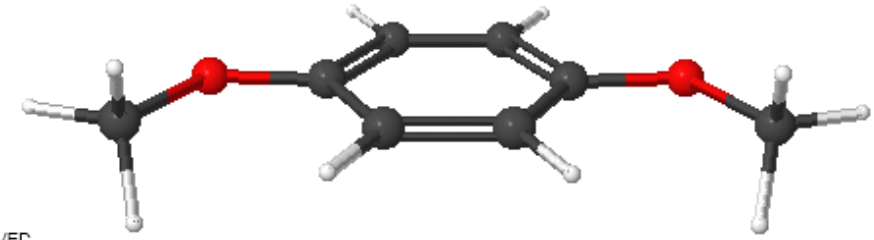


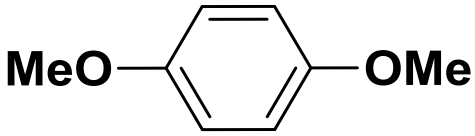
1,4-Dimethylbenzene

(*para*-Xylene)

300 MHz ^{1}H NMR
In CDCl3

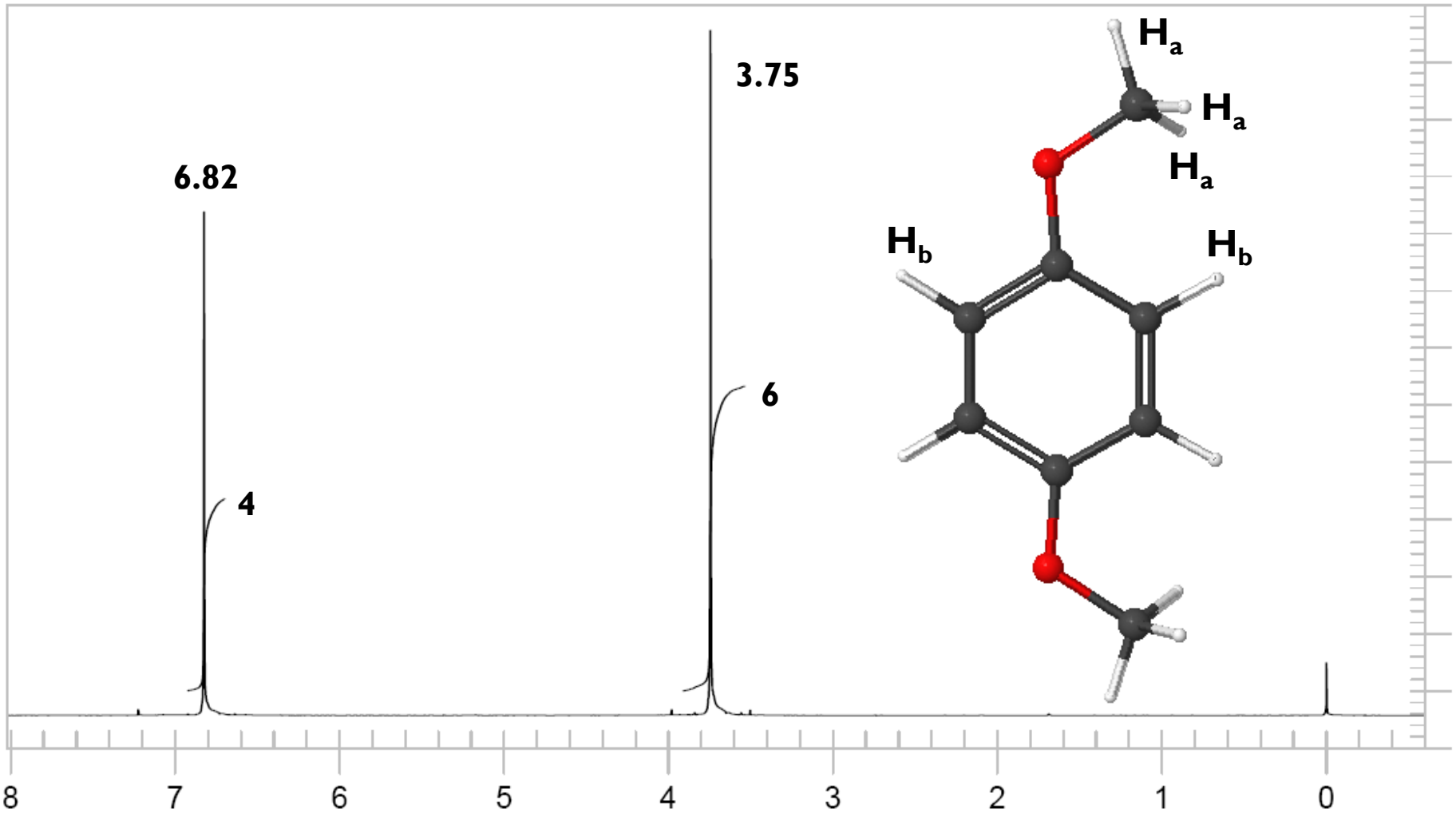


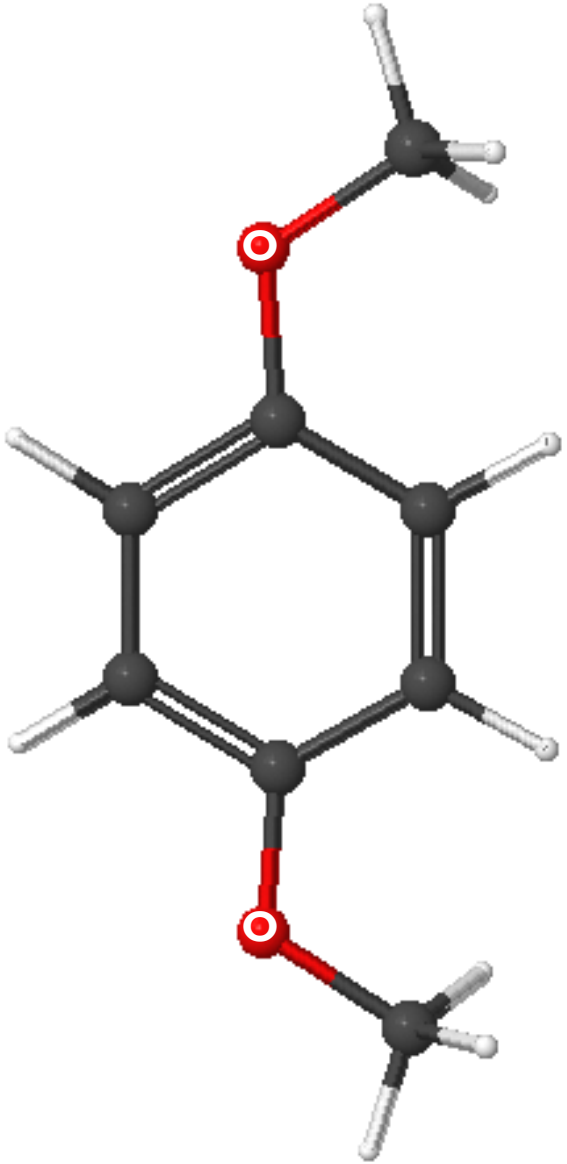




1,4-Dimethoxybenzene

300 MHz ^{1}H NMR
In CDCl3





Oxygen is a highly electronegative atom

Oxygen exerts a strong **electron-withdrawing** effect in the sigma-framework (i.e. along the C-O bond)

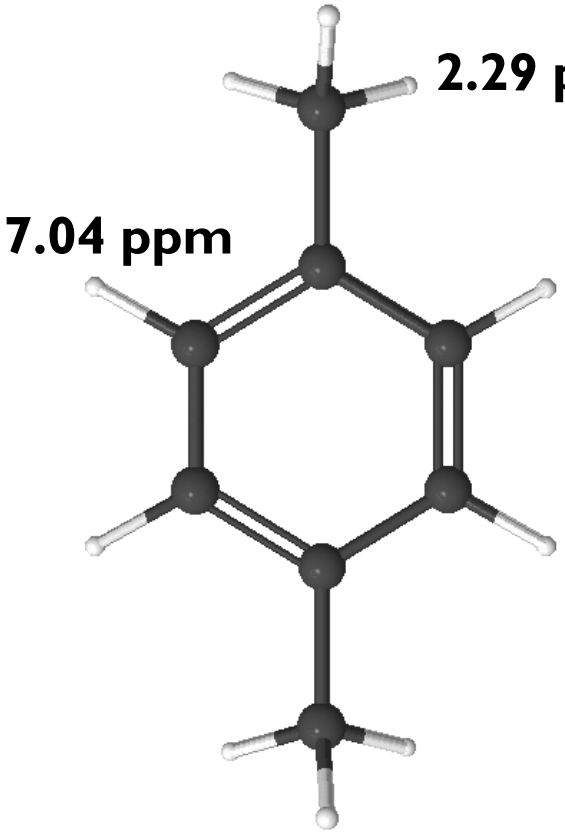
This **electron-withdrawing** effect reduces the degree of electron density around the Me-group C-atom

Electronegativity O = 3.44, C = 2.55, H = 2.20

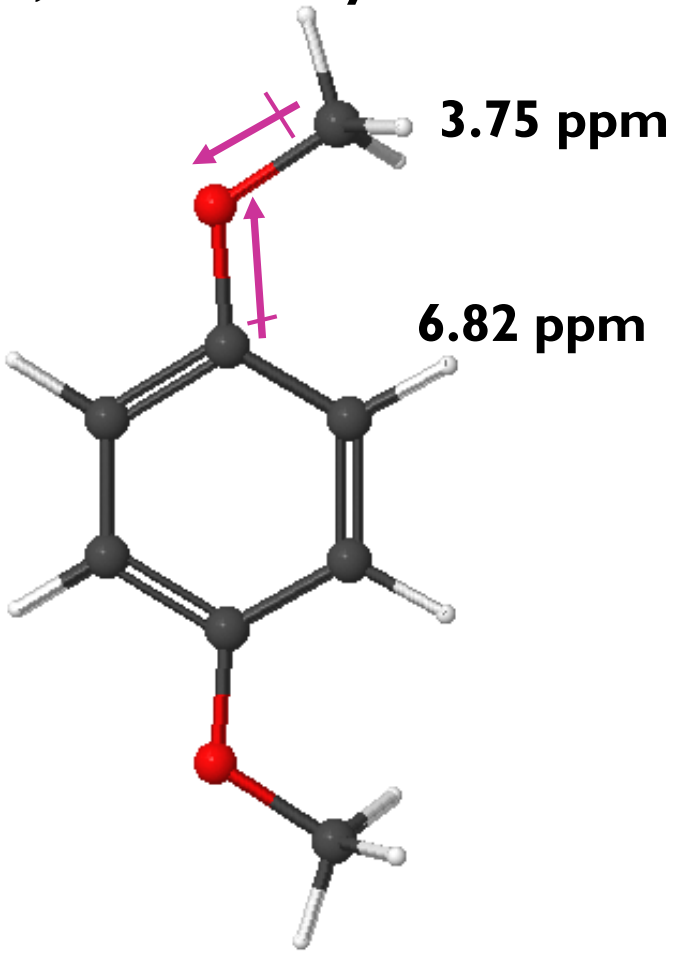
Shielding/deshielding are relative terms

The Me-group of 1,4-dimethoxybenzene is deshielded relative to the Me-group of 1,4-dimethylbenzene

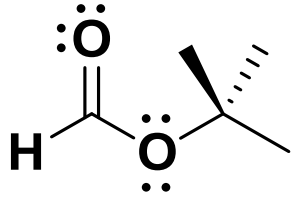
1,4-Dimethylbenzene



1,4-Dimethoxybenzene

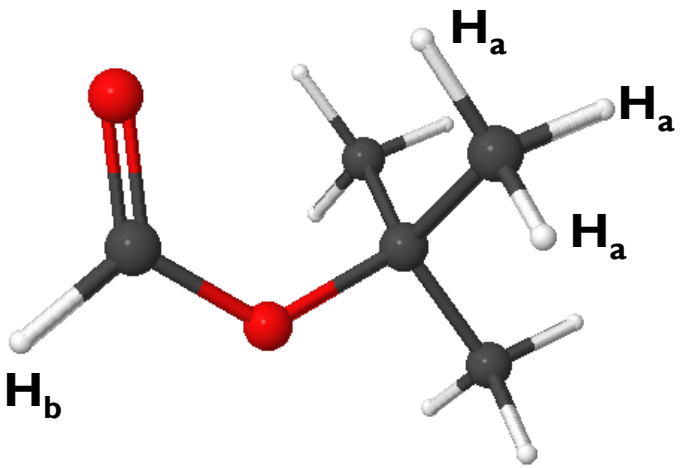


Electronegativity O = 3.44, C = 2.55, H = 2.20



***tert*-Butylformate**

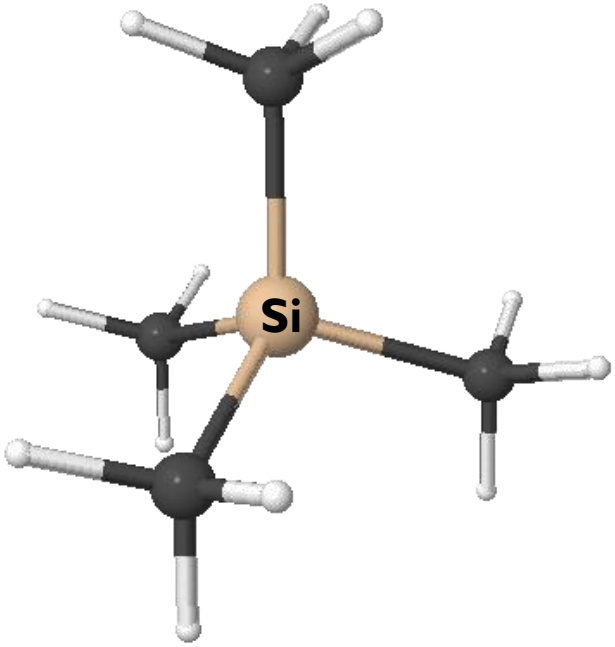
300 MHz ^{1}H NMR
In CDCl3



1.50
9
Ha

8.00
Hb
1

9 8 7 6 5 4 3 2 1 0



$SiMe_4$ = TMS = Tetramethylsilane

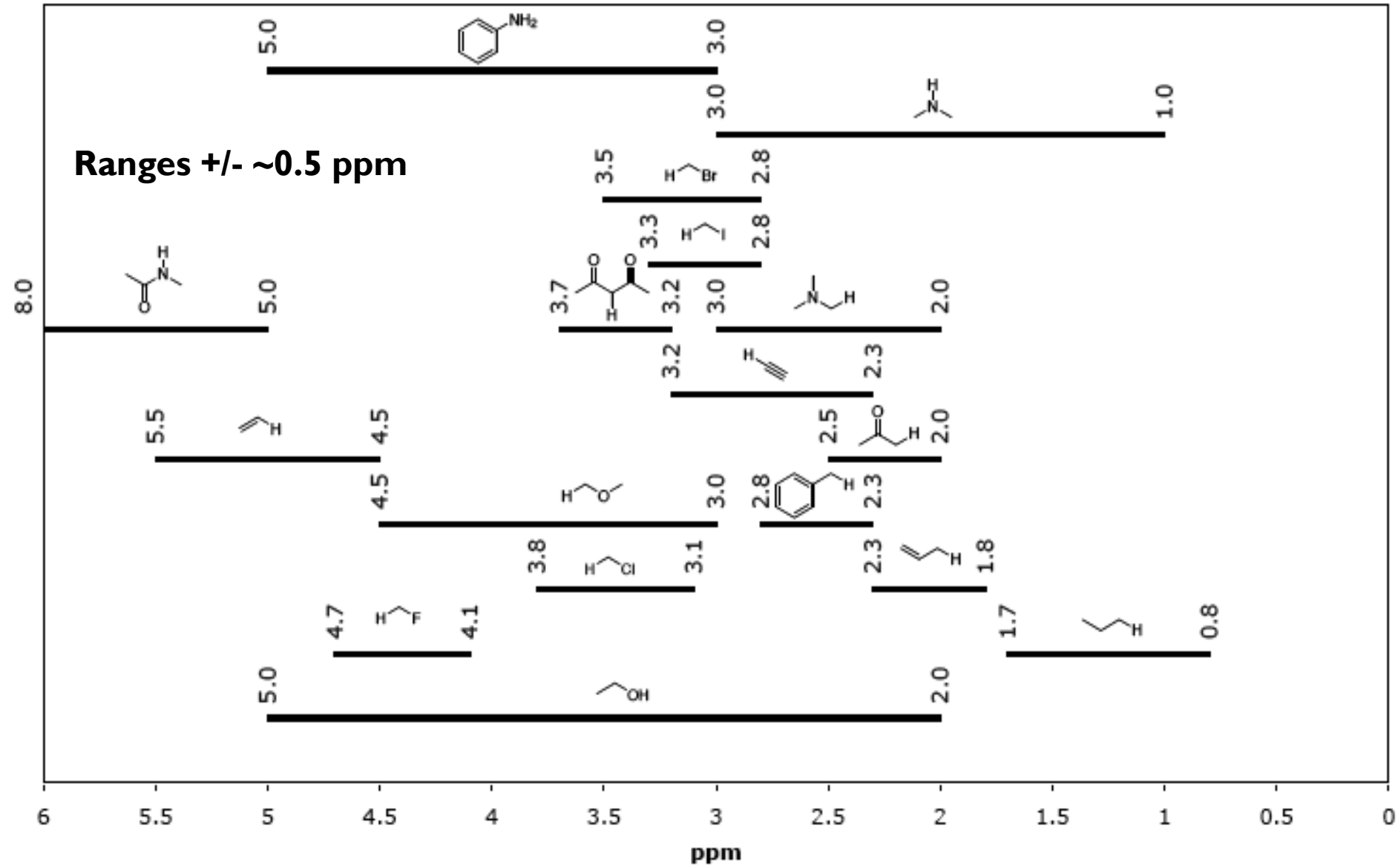
0.00 ppm reference compound

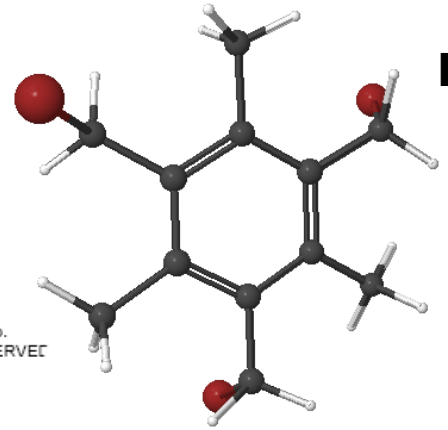
Why use TMS?

- **chemically inert (won't react with most molecules)**
- **protons are strongly shielded**
- **signal is strong and unsplit**
- **volatile (easily removed)**
- **inexpensive**

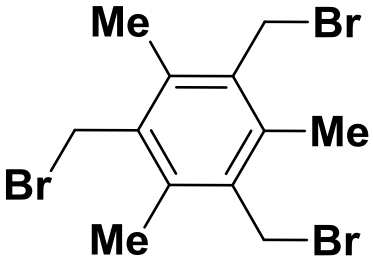
<u>Don't assign the TMS signal as part of your molecule!</u>

^{1}H-NMR Chemical Shift Table





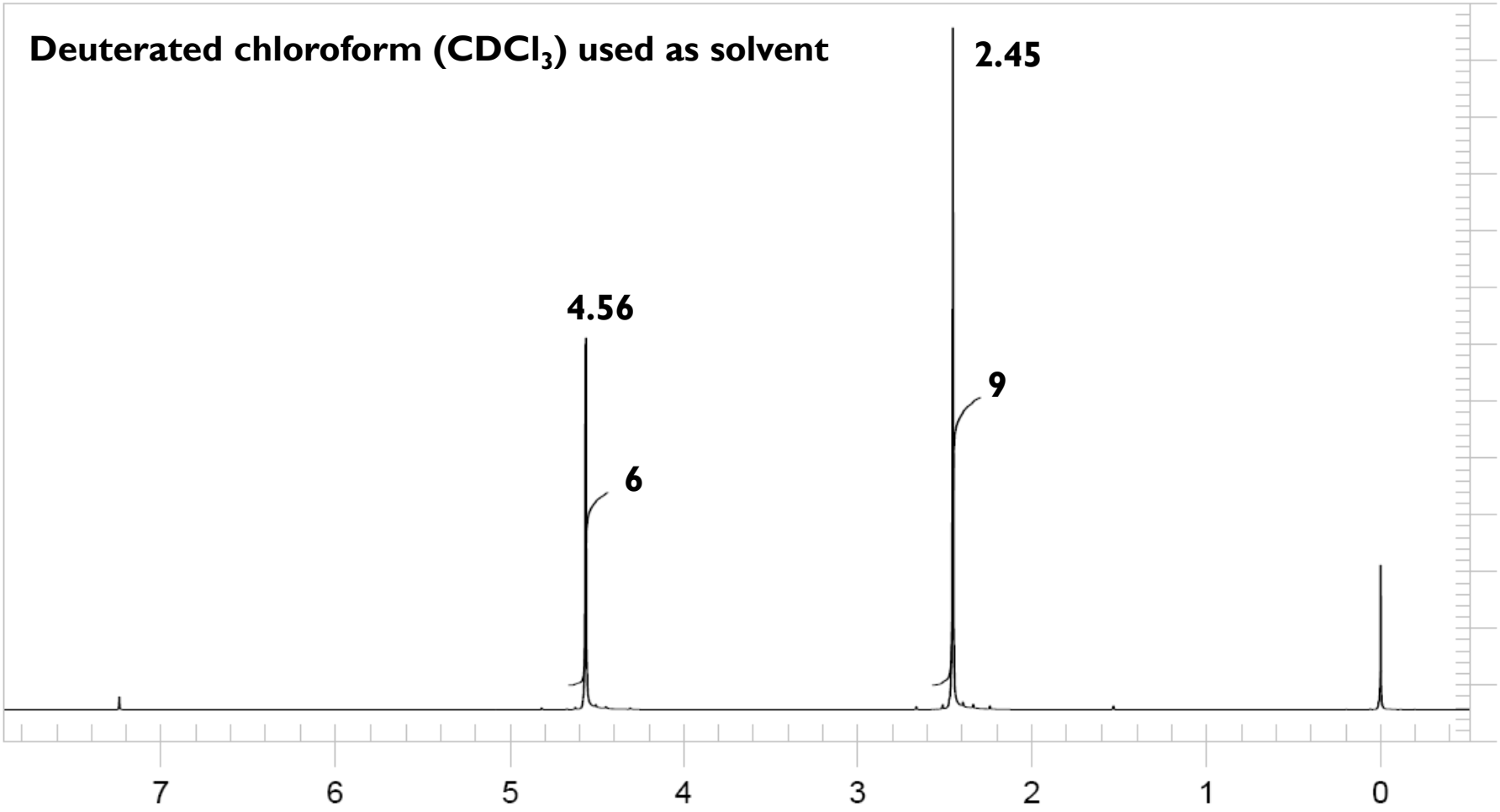
Electronegativity **Br = 2.96**
C = 2.55



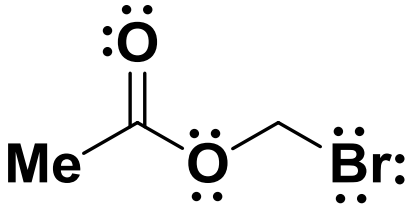
2,4,6-Tris(bromomethyl)mesitylene

300 MHz ^{1}H NMR
In CDCl3

Deuterated chloroform ($CDCl_3$) used as solvent



Reporting ^{1}H-NMR data



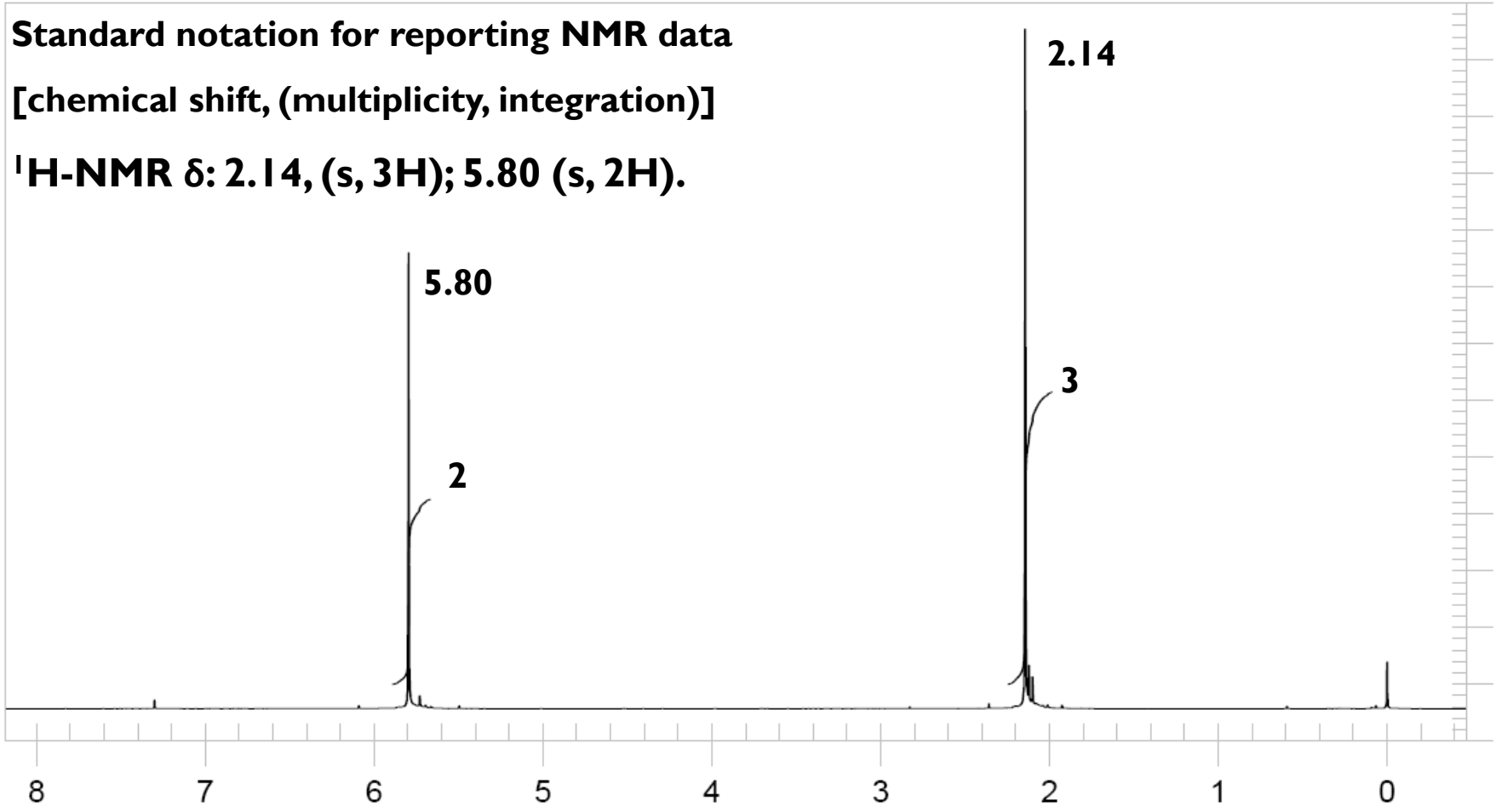
Bromomethyl acetate

300 MHz ^{1}H NMR
In CDCl3

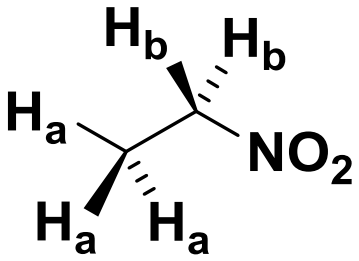
Standard notation for reporting NMR data

[chemical shift, (multiplicity, integration)]

^{1}H-NMR δ: 2.14, (s, 3H); 5.80 (s, 2H).

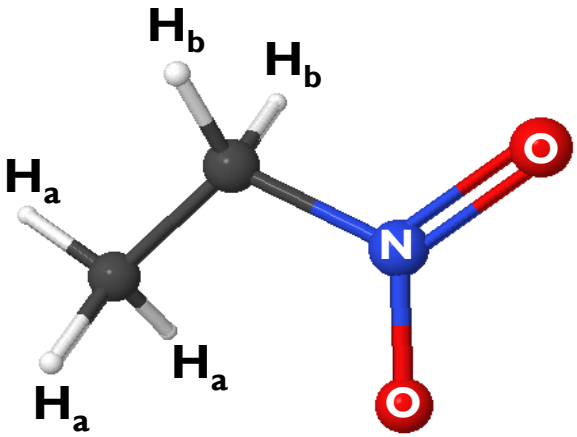


Spin-spin coupling



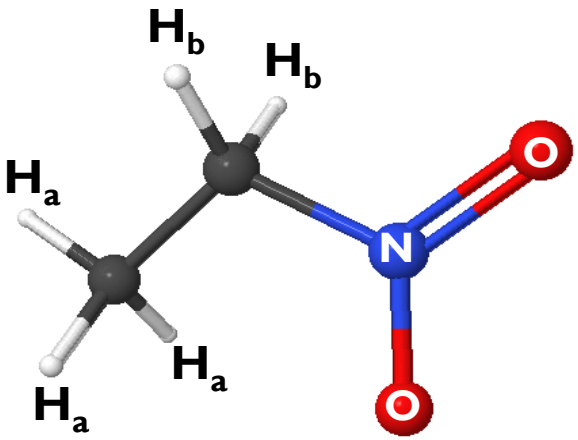
Nitroethane

300 MHz ^{1}H NMR
In CDCl3



Electronegativity O = 3.44, N = 3.04, C = 2.55

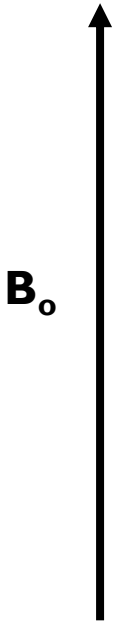
How do neighboring non-equivalent protons interact?



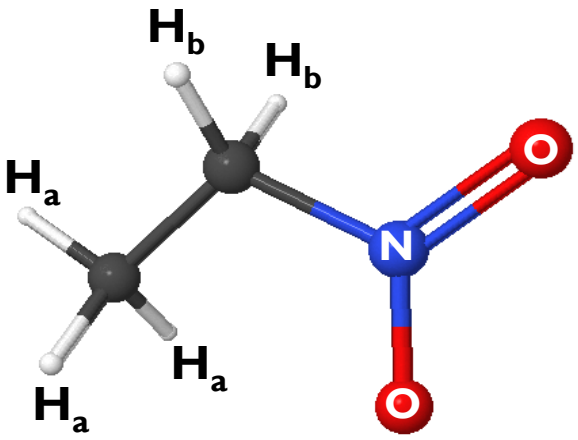
Consider how H_b protons interact with H_a protons

H_b protons align with or against direction of B_o

3 different combinations of H_b spin states



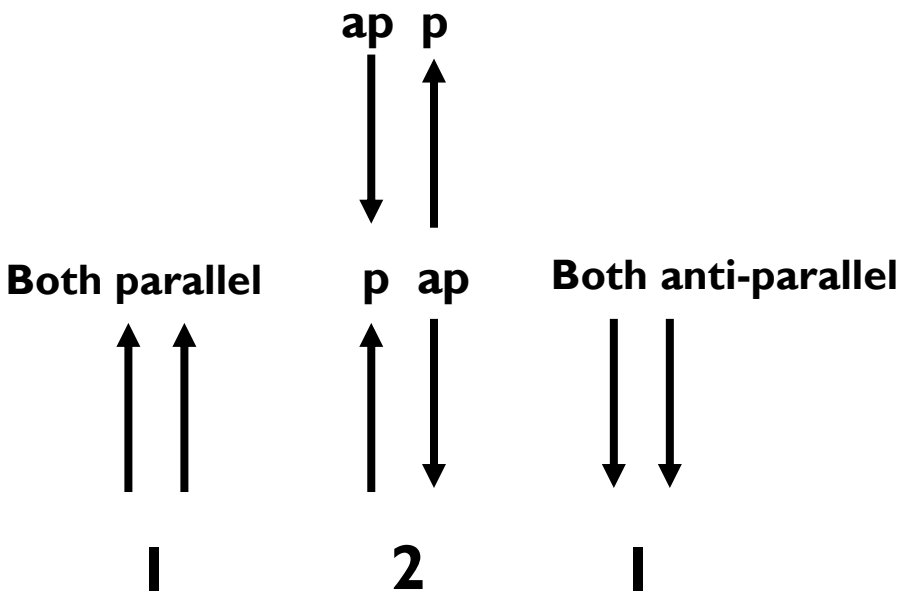
How do neighboring non-equivalent protons interact?



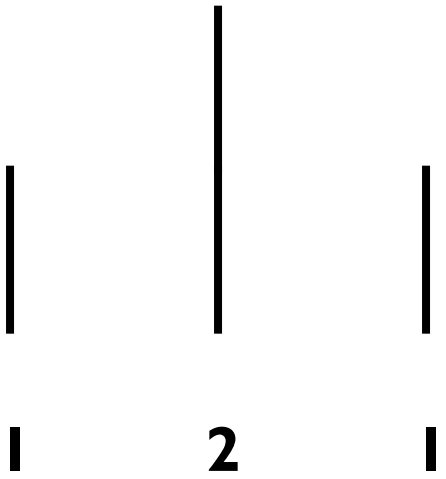
Consider how H_b protons interact with H_a protons

H_b protons align with or against direction of B_o

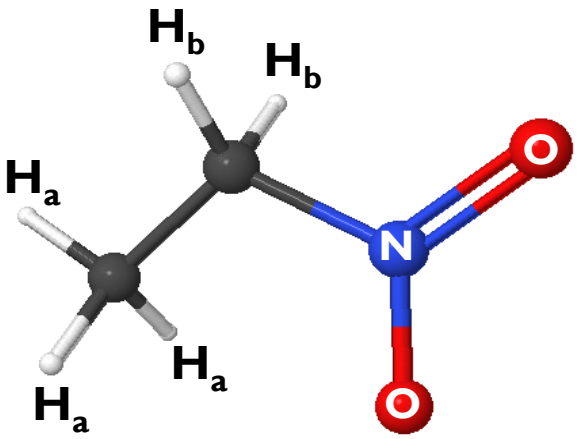
3 different combinations of H_b spin states



Signal from H_a split into a 1:2:1 triplet by H_b

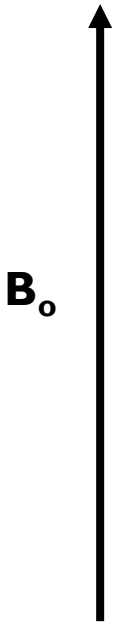


How do neighboring non-equivalent protons interact?

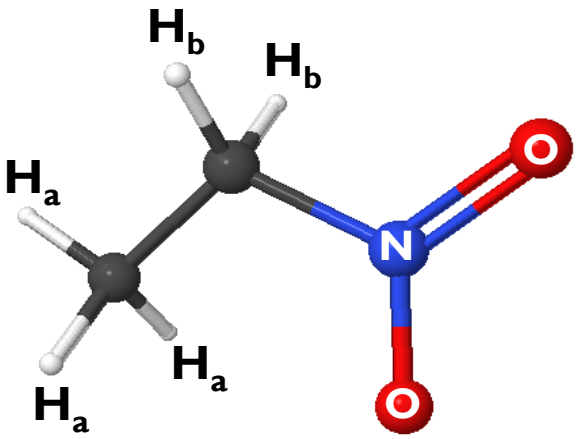


Consider how H_a protons interact with H_b protons

4 different combinations of H_a spin states



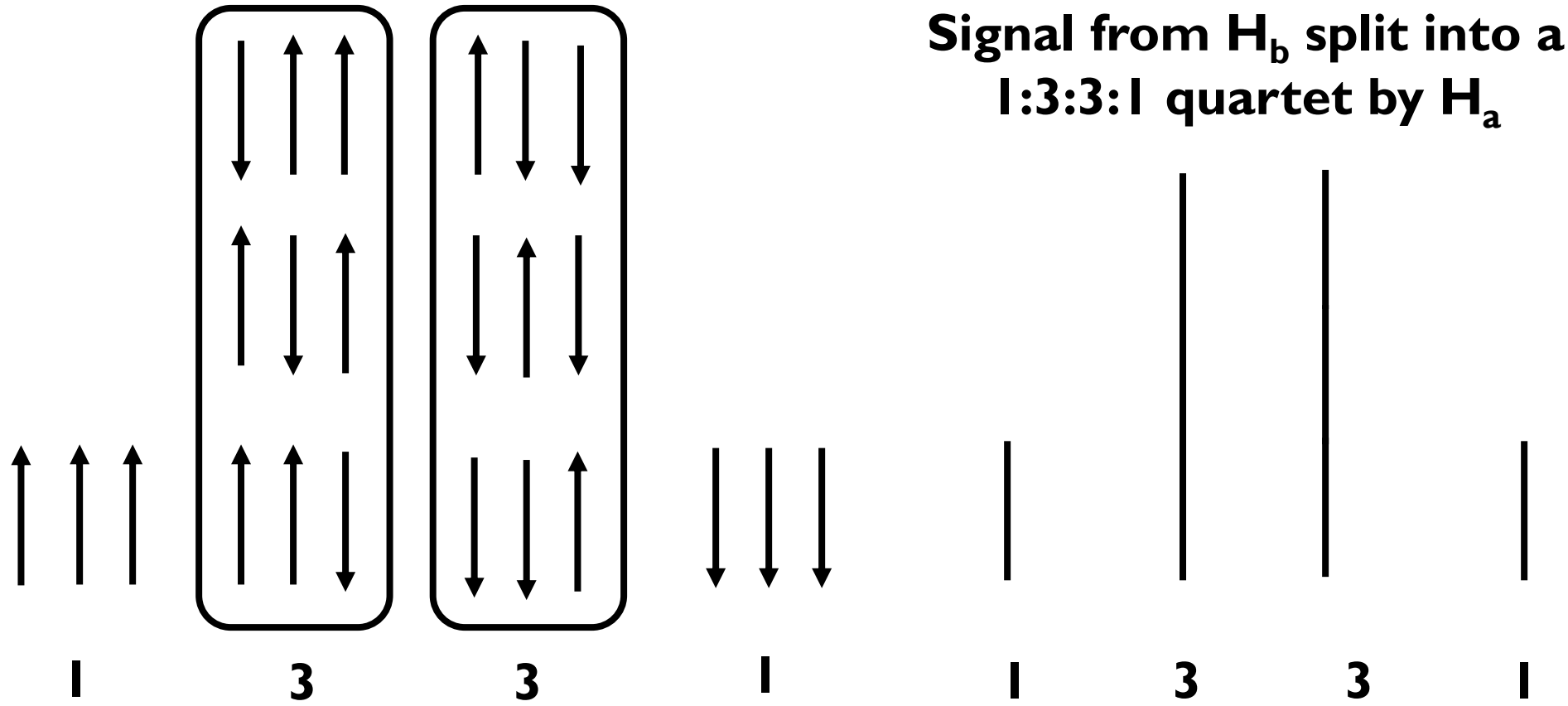
How do neighboring non-equivalent protons interact?



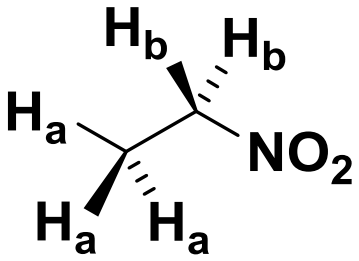
Consider how H_a protons interact with H_b protons

4 different combinations of H_a spin states

Signal from H_b split into a 1:3:3:1 quartet by H_a

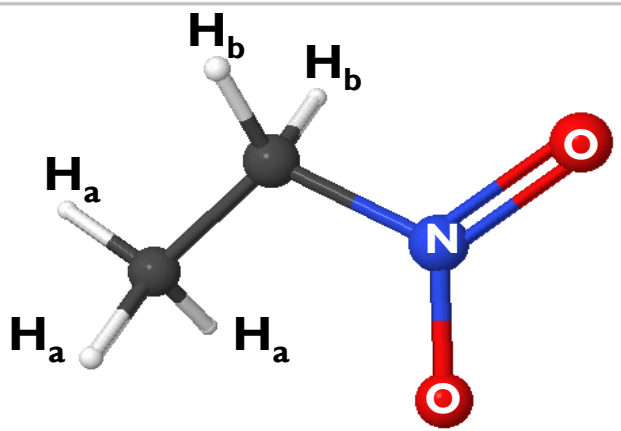


Spin-spin splitting



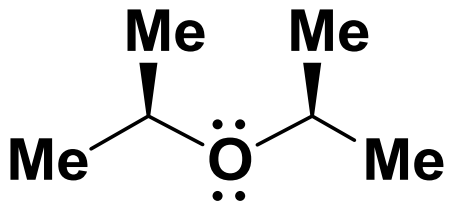
Nitroethane

300 MHz ^{1}H NMR
In CDCl3



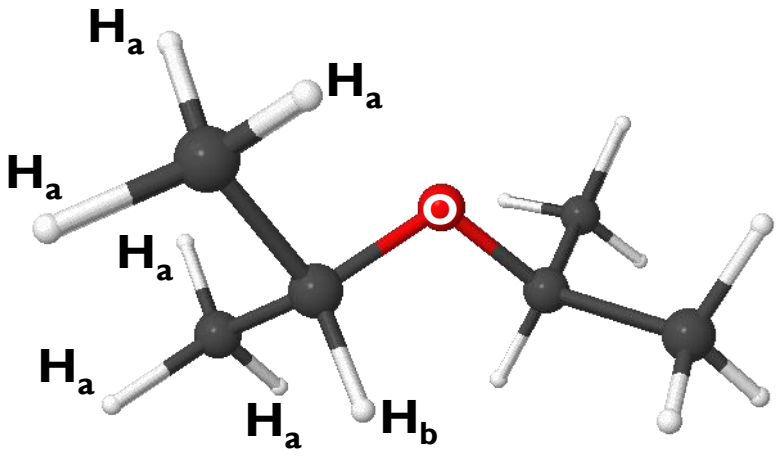
n + 1 rule

n = # non-equivalent neighboring protons



Diisopropylether

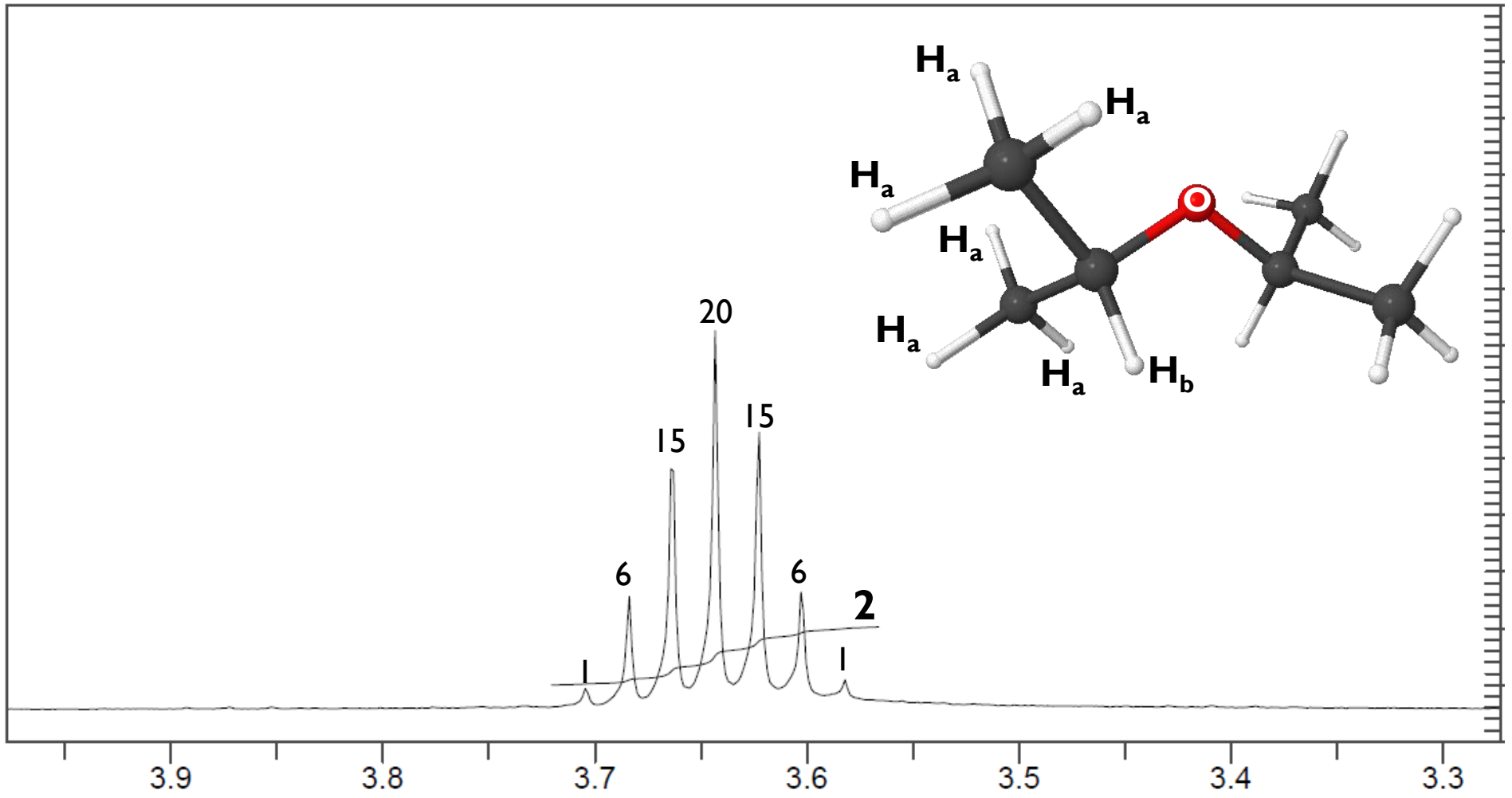
300 MHz ^{1}H NMR
In CDCl3



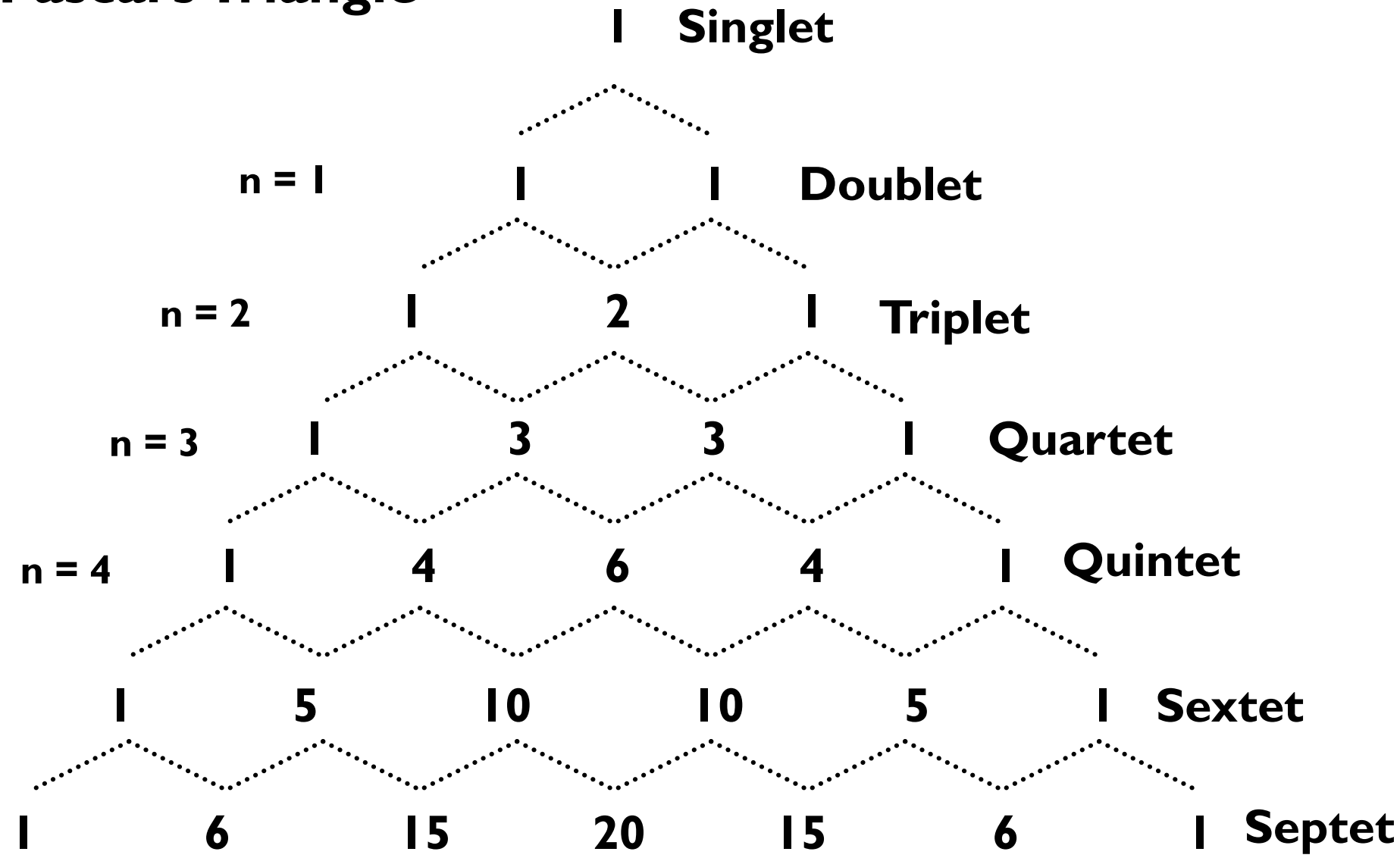
n + 1 rule

Coupling constant J (Hz) – indicates strength of coupling

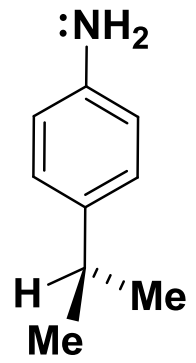
J ~ 7 Hz for alkyl (sp^3) systems



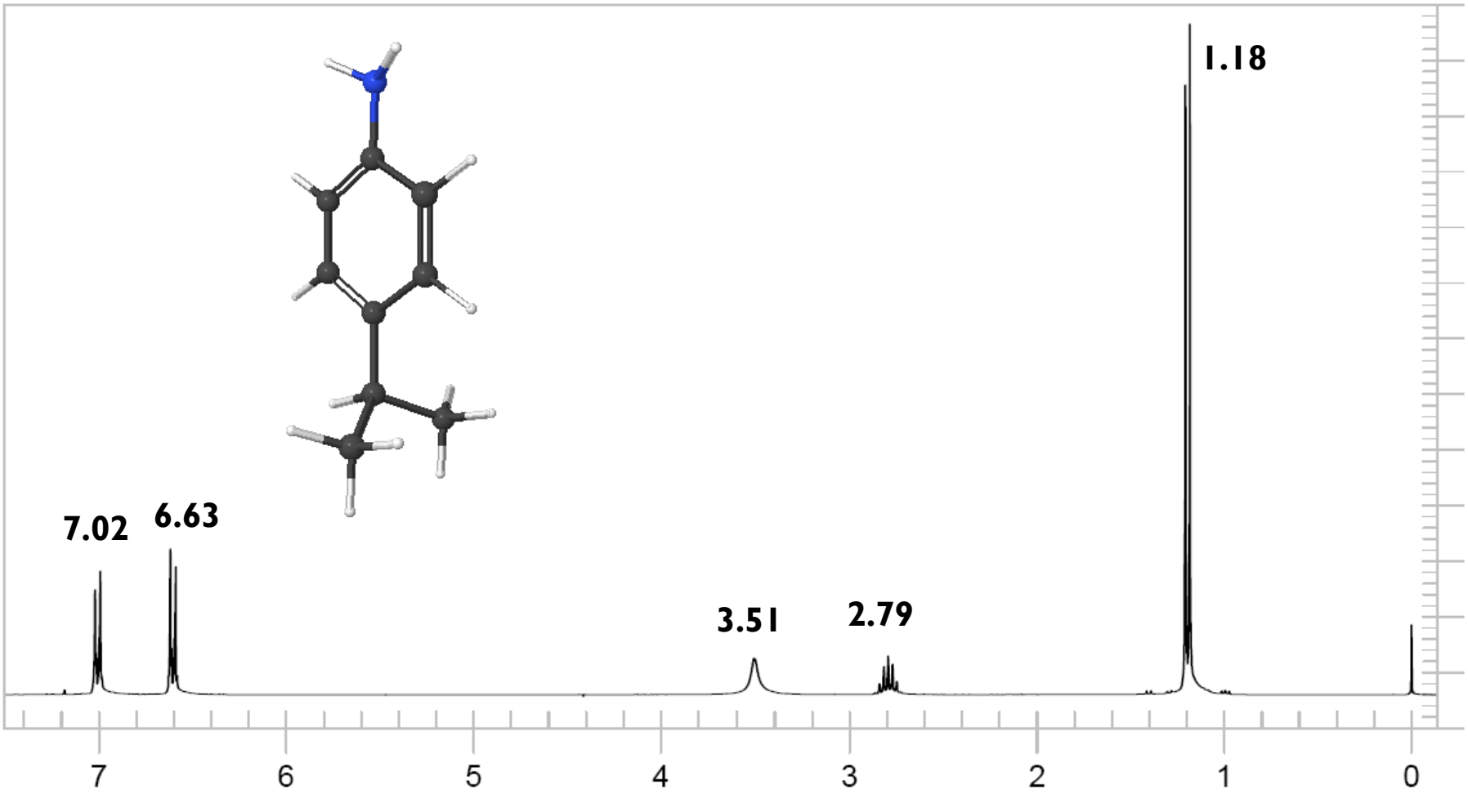
Pascal's Triangle

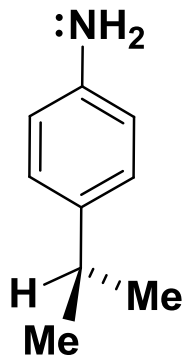


300 MHz ^{1}H NMR
In CDCl3



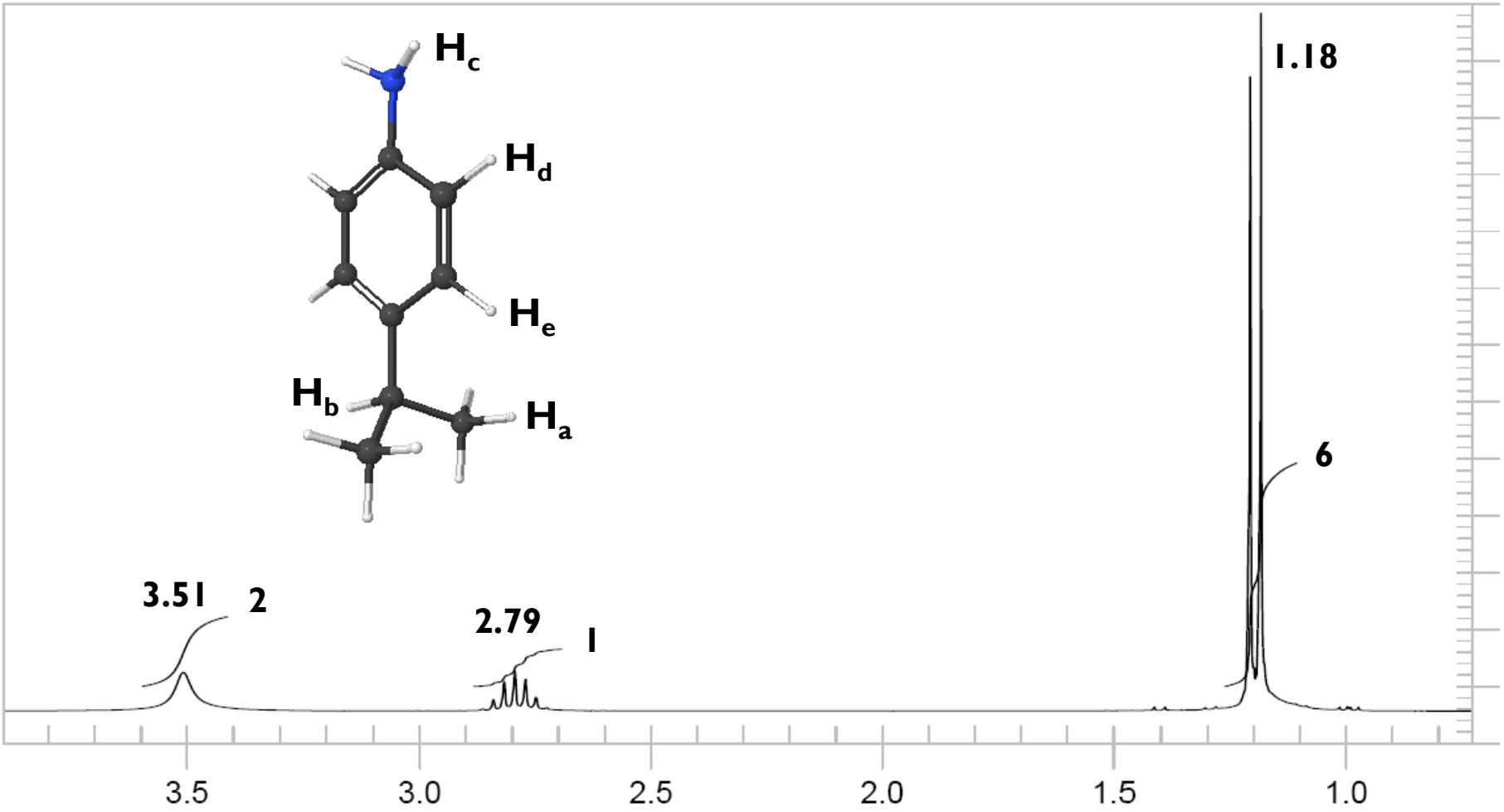
4-*iso*propylaniline





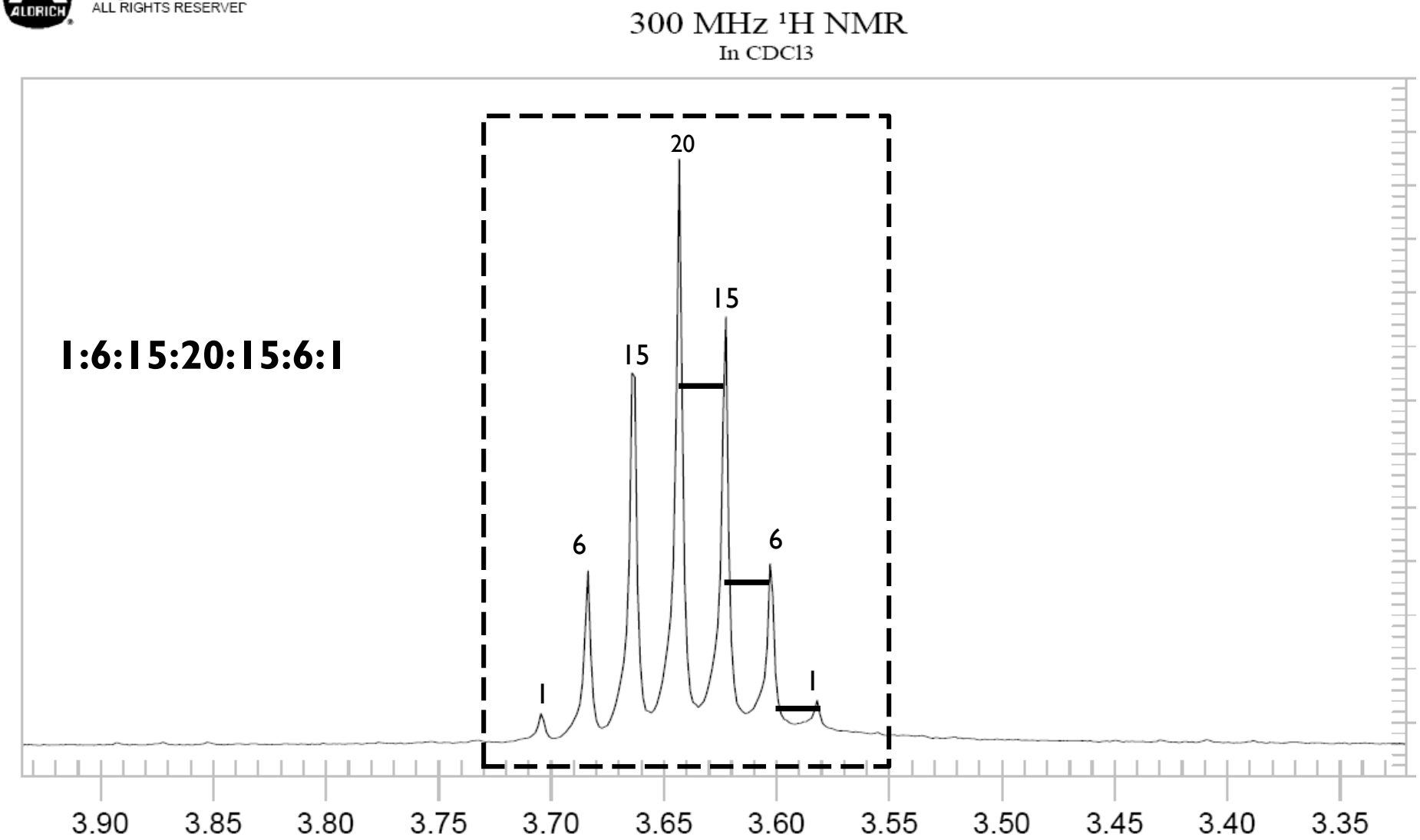
4-*iso*propylaniline

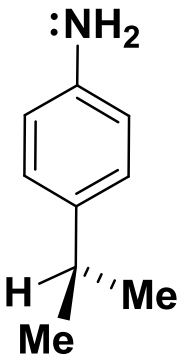
300 MHz ^{1}H NMR
In CDCl3



Coupling constant *J* (Hz) – indicates strength of coupling

J ~ 7 Hz for alkyl (sp^3) systems





4-*iso*propylaniline

300 MHz ^{1}H NMR
In CDCl3