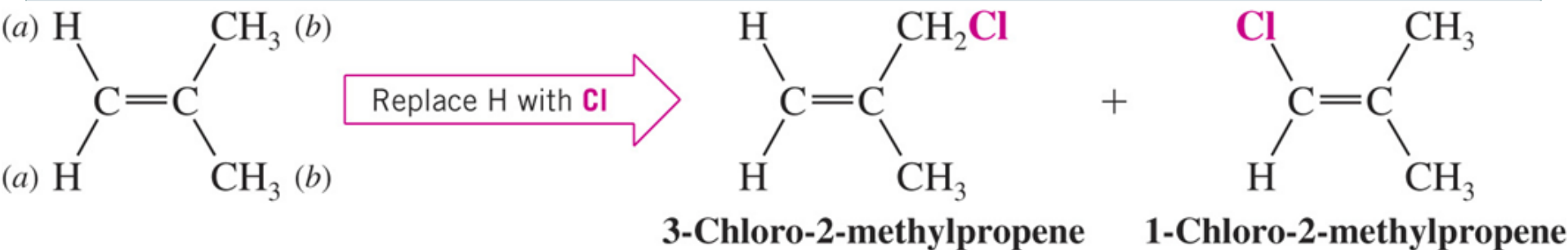


Homotopic H's

○ Homotopic Hydrogens

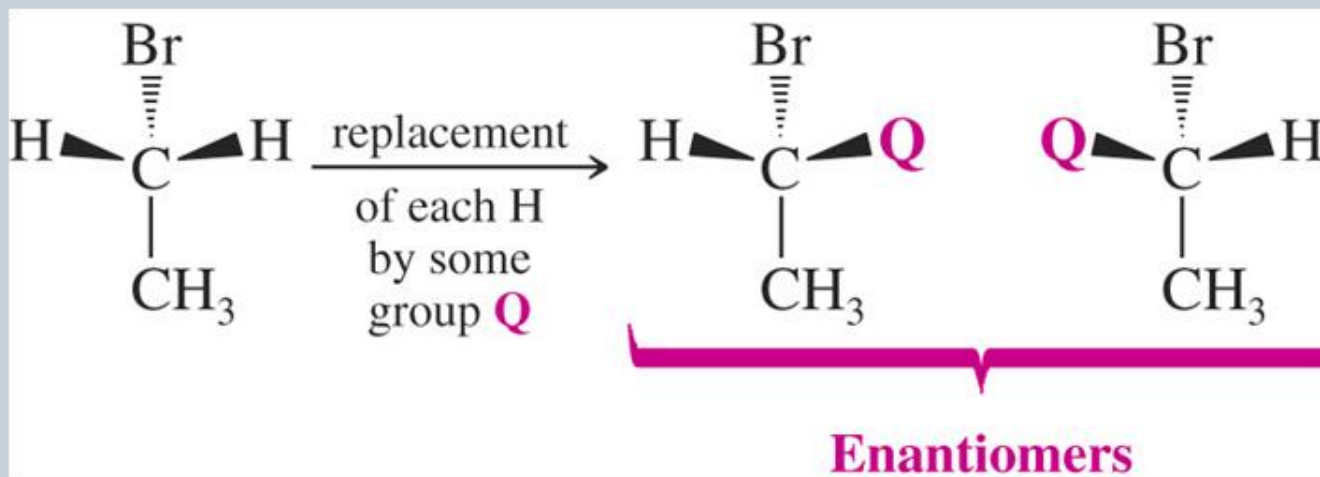
- ✦ Hydrogens are chemically equivalent or homotopic if replacing each one in turn by the same group would lead to an identical compound



Enantiotopic H's

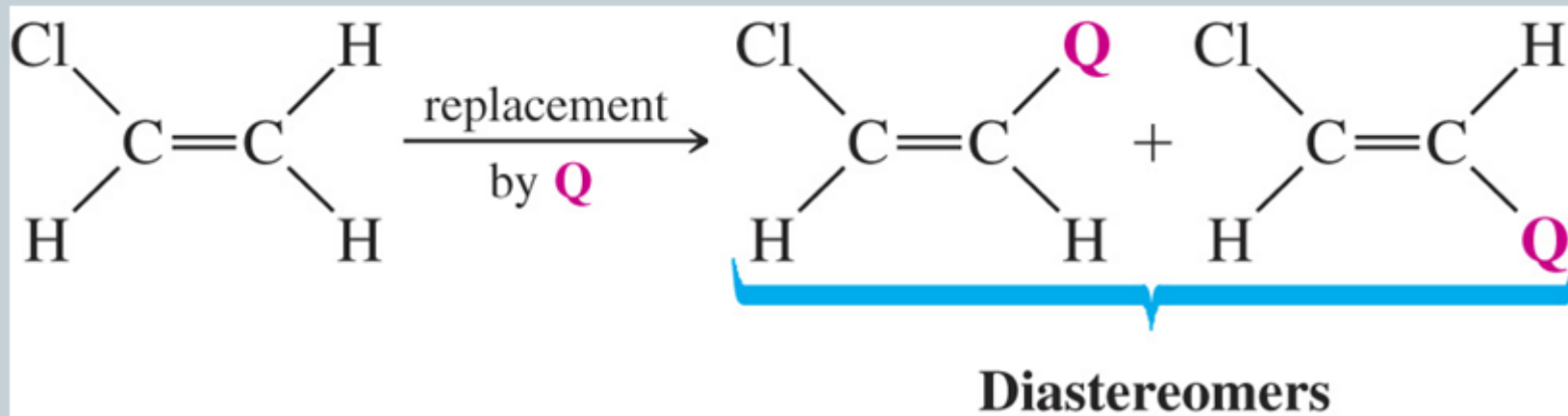


- ✦ If replacement of each of two hydrogens by some group leads to enantiomers, those hydrogens are enantiotopic

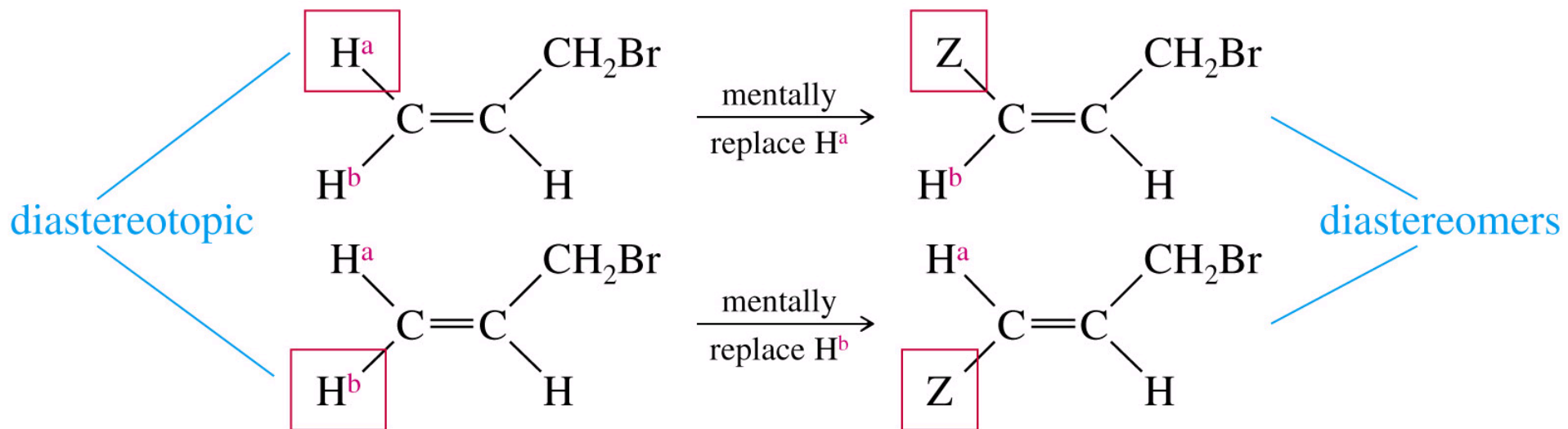


Diastereotopic H's

- ✦ If replacement of each of two hydrogens by some group leads to diastereomers, the hydrogens are diastereotopic
 - Diastereotopic hydrogens have different chemical shifts and will give different signals



Vinyl Protons





Integração

INTEGRATION OF A PEAK

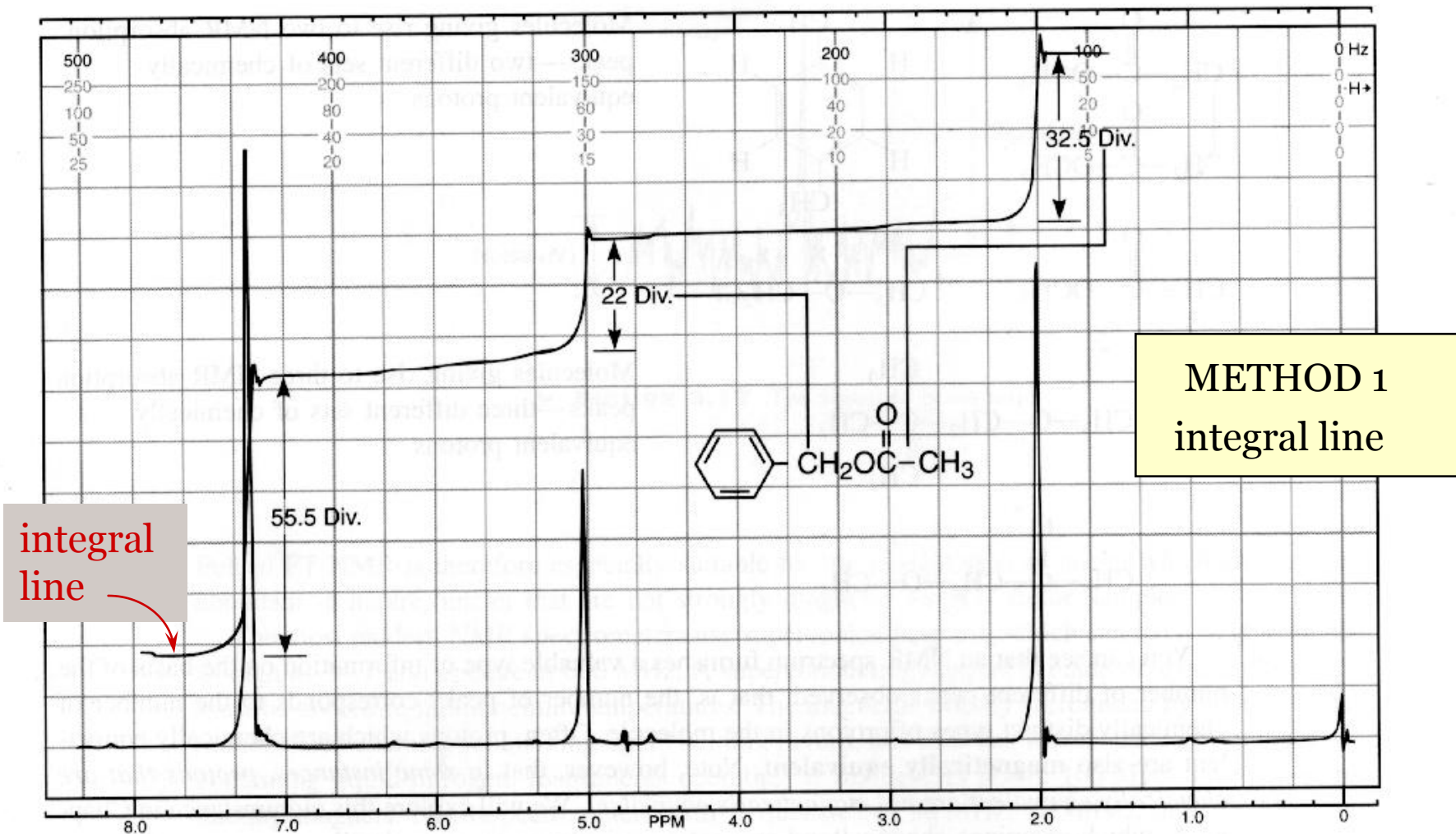
Not only does each different type of hydrogen give a distinct peak in the NMR spectrum, but we can also tell the relative numbers of each type of hydrogen by a process called integration.

Integration = determination of the area under a peak

The area under a peak is proportional to the number of protons that generate the peak.

Benzyl Acetate

The integral line rises an amount proportional to the number of H in each peak



integral
line

METHOD 1
integral line

$$55 : 22 : 33 = \underline{5 : 2 : 3}$$

simplest ratio
of the heights

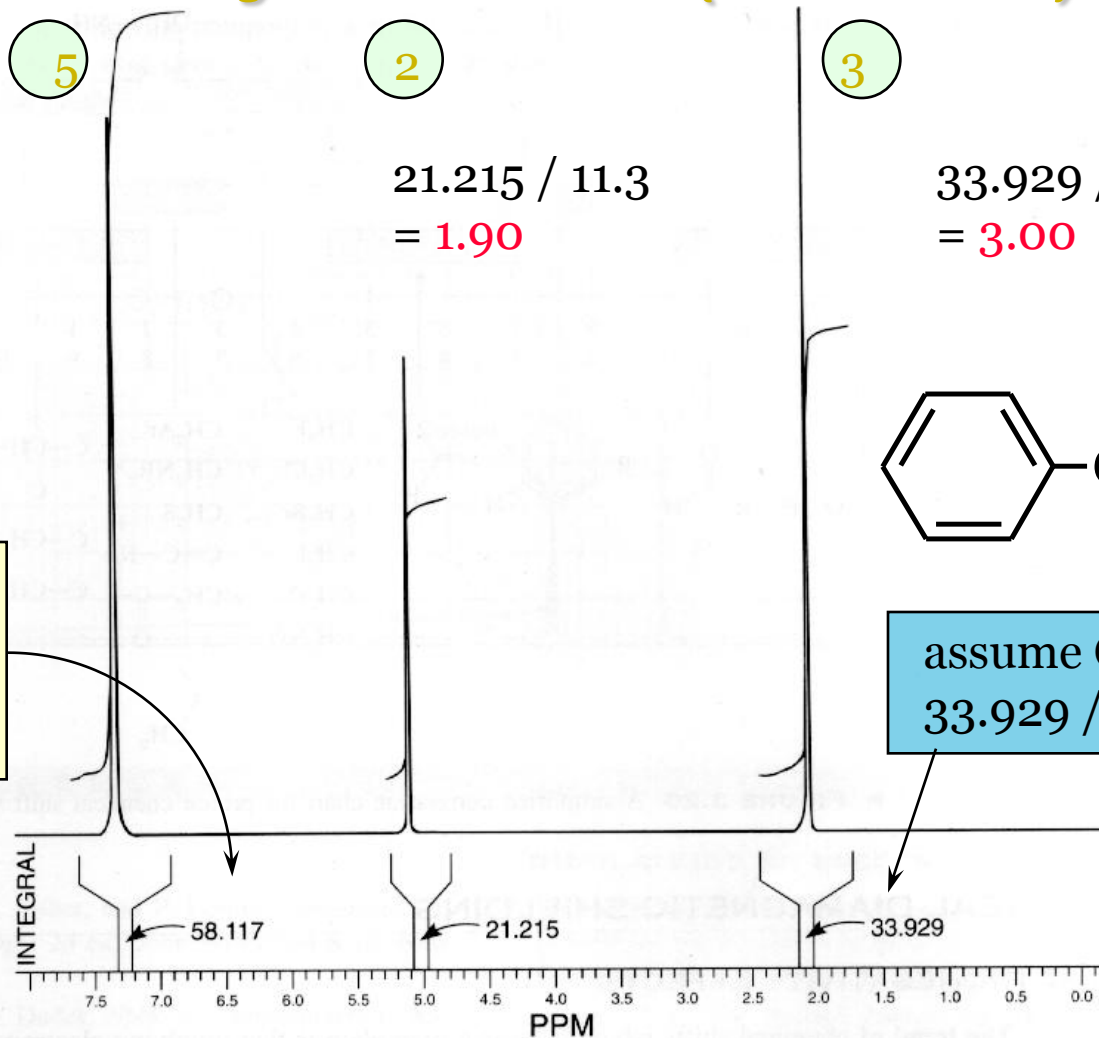
Benzyl Acetate (FT-NMR)

Actually :

$$58.117 / 11.3 = 5.14$$

$$21.215 / 11.3 = 1.90$$

$$33.929 / 11.3 = 3.00$$



METHOD 2

digital
integration

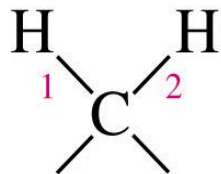
assume CH₃
33.929 / 3 = 11.3 per H

Integrals are
good to about
10% accuracy.

Modern instruments report the integral as a number.

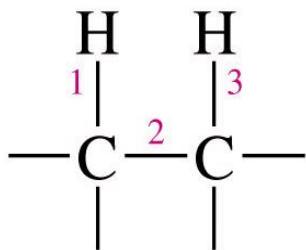
SPIN-SPIN SPLITTING

Bonded to the same carbon: two bonds between protons



spin-spin splitting is normally observed
(if nonequivalent)

Bonded to adjacent carbons: three bonds between protons



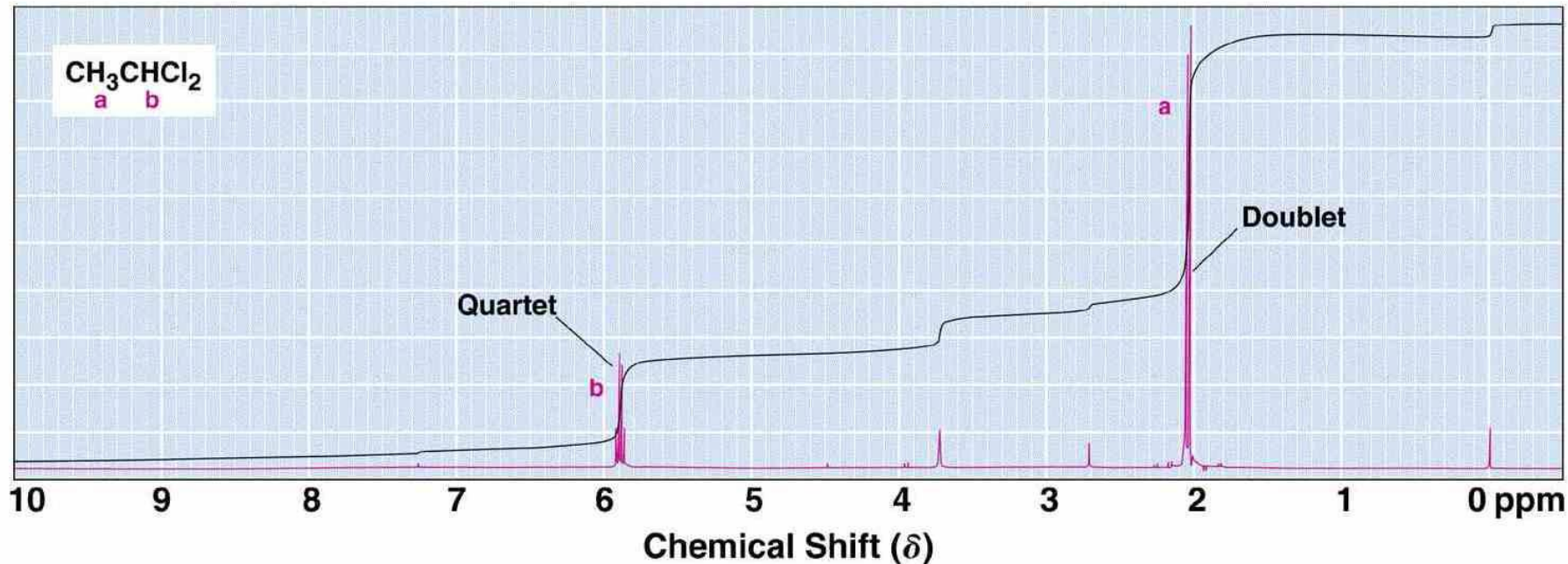
spin-spin splitting is normally observed
(this is the most common case)

SIGNAL SPLITTING; THE $(N + 1)$ RULE

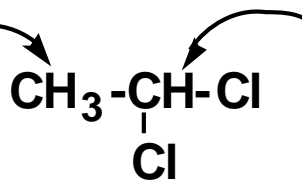


- **Peak:** the units into which an NMR signal is split; doublet, triplet, quartet, etc.
- **Signal splitting:** splitting of an NMR signal into a set of peaks by the influence of neighboring nonequivalent hydrogens
- **$(n + 1)$ rule:** if a hydrogen has n hydrogens nonequivalent to it but equivalent among themselves on the same or adjacent atom(s), its ^1H -NMR signal is split into $(n + 1)$ peaks

Signal Splitting ($n + 1$)



For these hydrogens, $n = 1$;
their signal is split into
 $(1 + 1) = 2$ peaks; a doublet

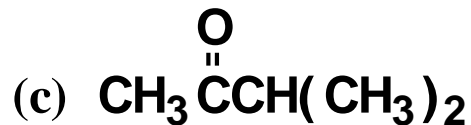
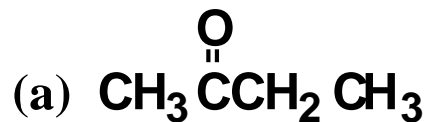


For this hydrogen, $n = 3$;
its signal is split into
 $(3 + 1) = 4$ peaks; a quartet

Signal Splitting ($n + 1$)



Problem: predict the number of ^1H -NMR signals and the splitting pattern of each

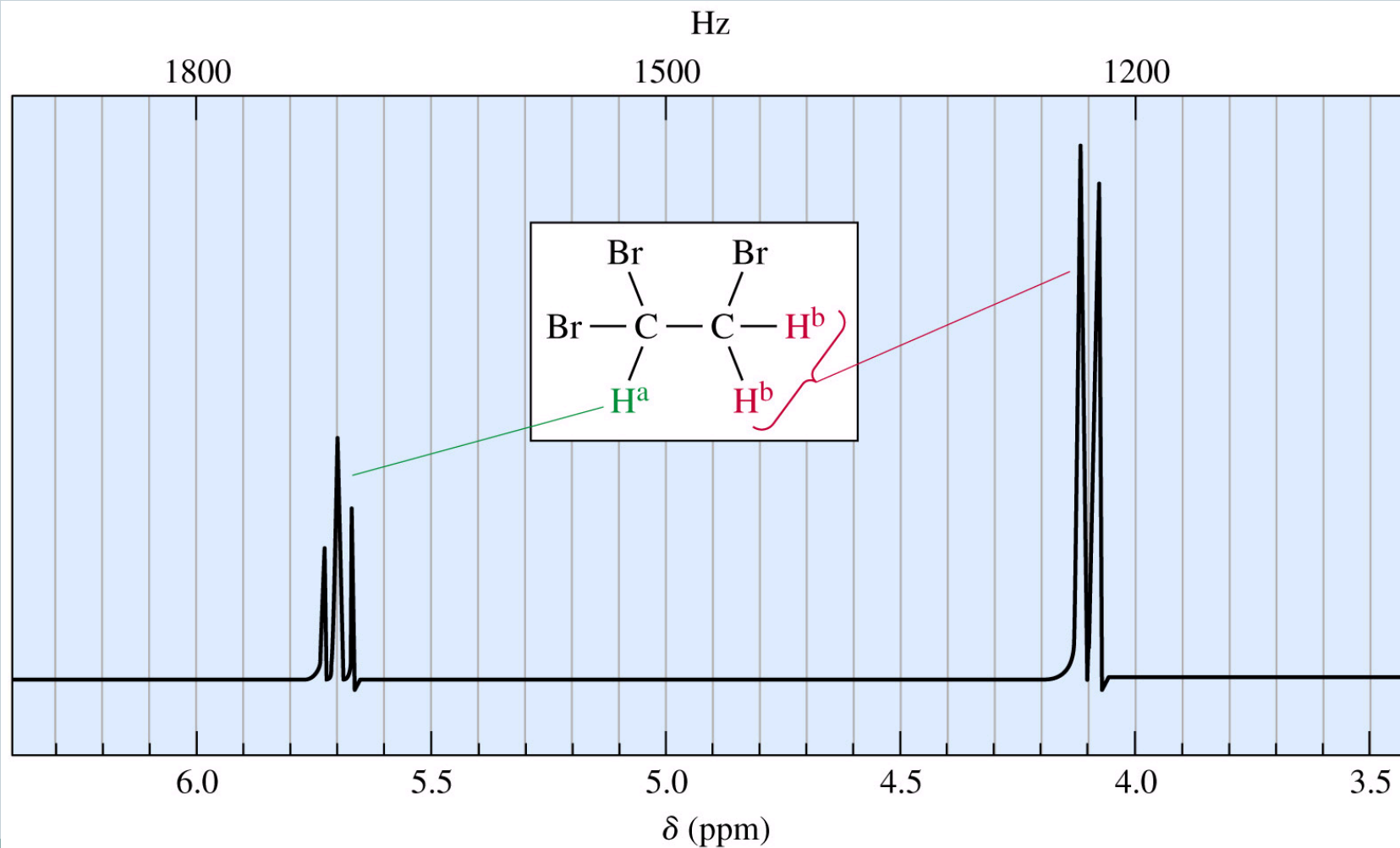


Origins of Signal Splitting

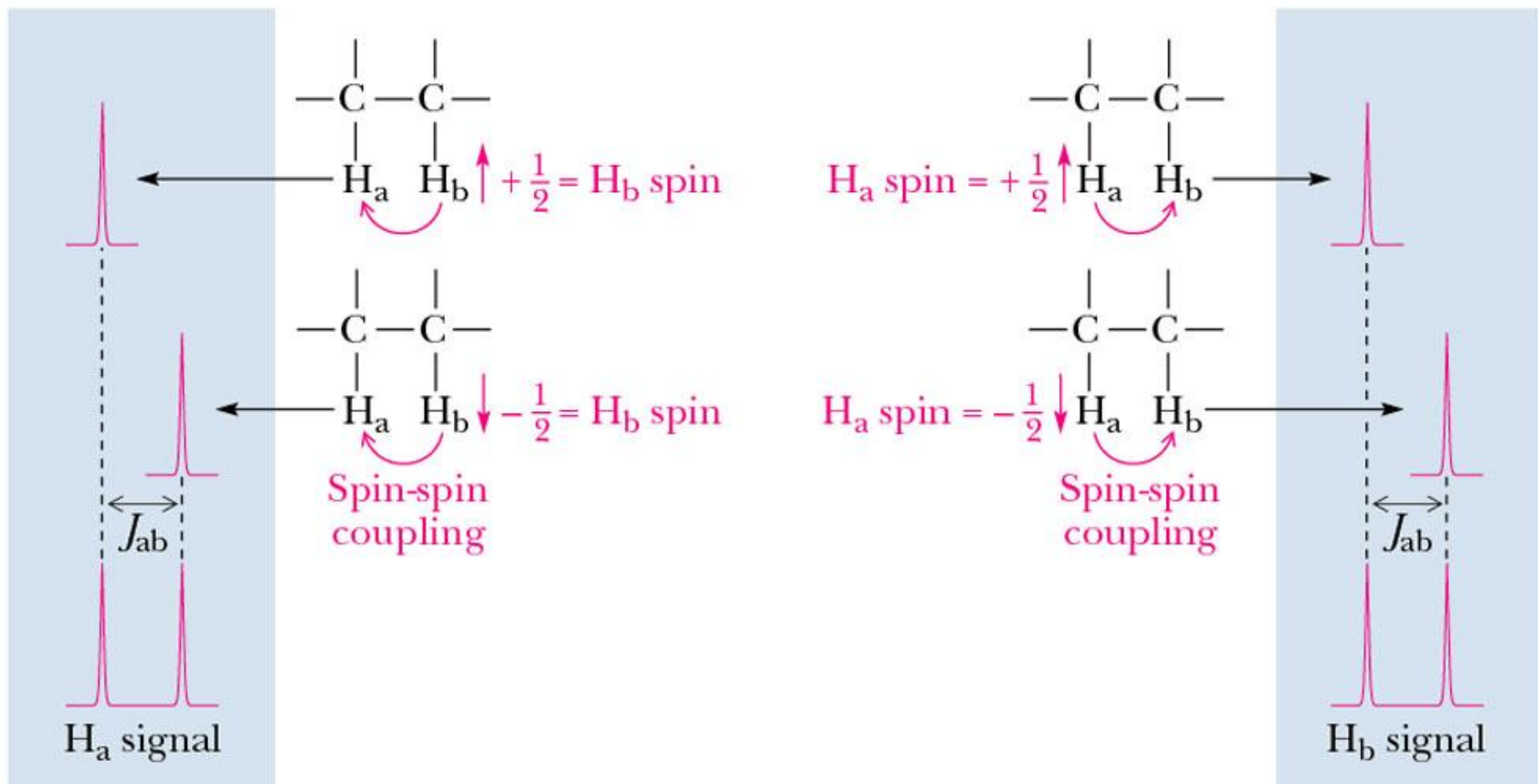


- **Signal coupling:** an interaction in which the nuclear spins of adjacent atoms influence each other and lead to the splitting of NMR signals
- **Coupling constant (J):** the separation on an NMR spectrum (in hertz) between adjacent peaks in a multiplet;
 - a quantitative measure of the influence of the spin-spin coupling with adjacent nuclei

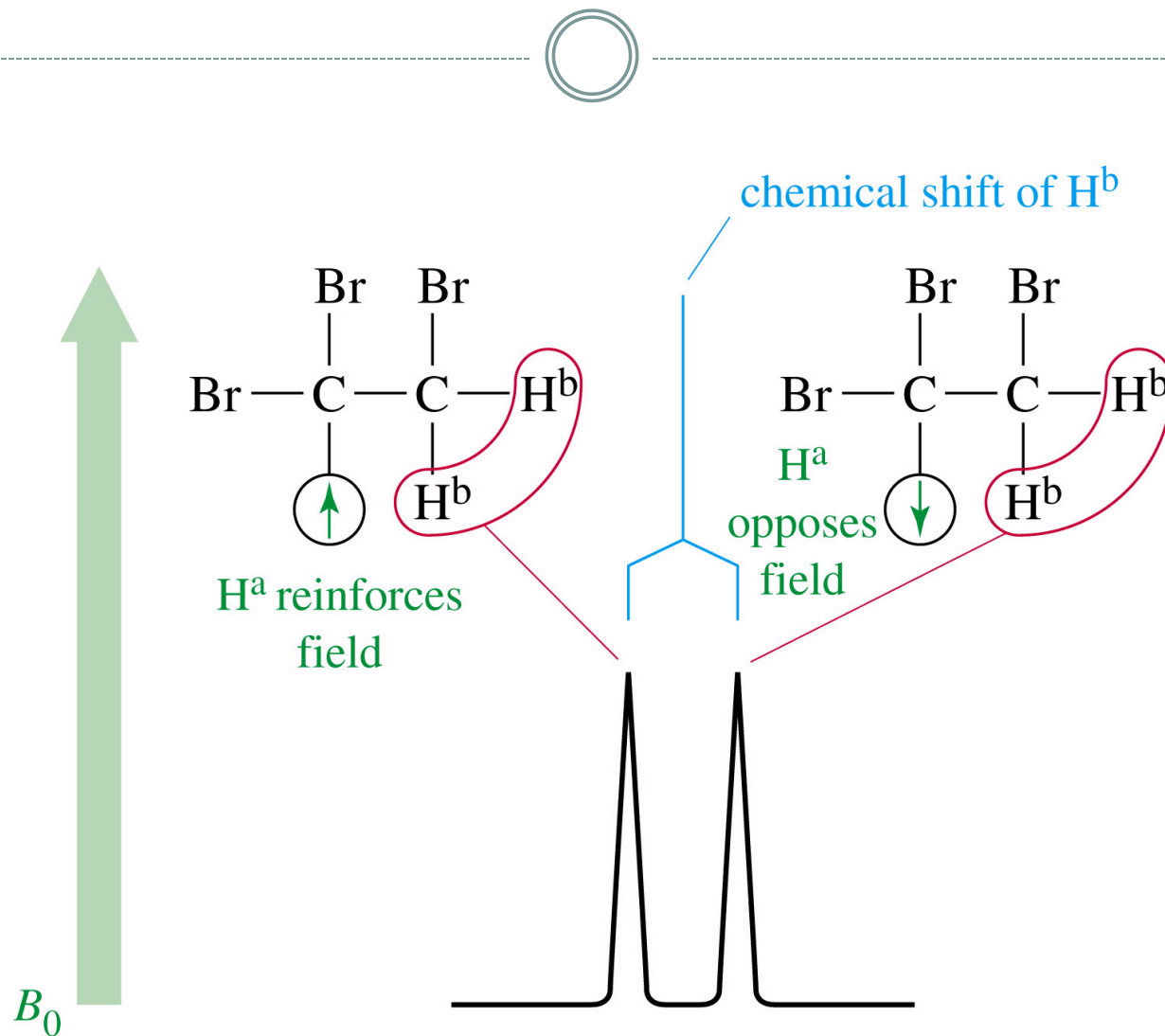
1,1,2-Tribromoethane



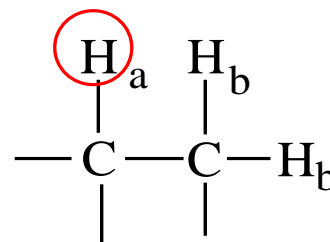
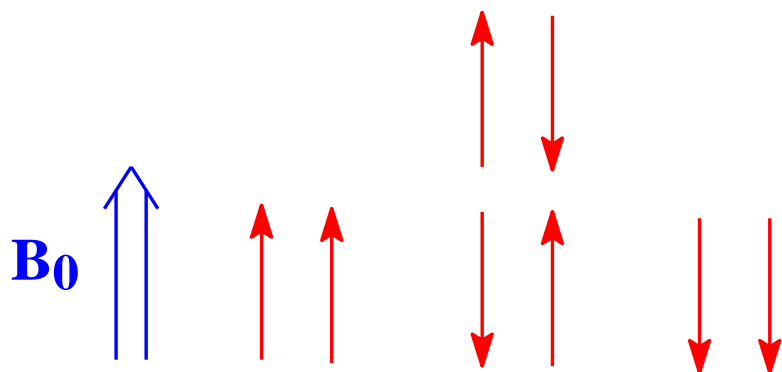
Origins of Signal Splitting



H_b in 1,1,2-Tribromoethane



THE TRIPLET IN ^1H NMR

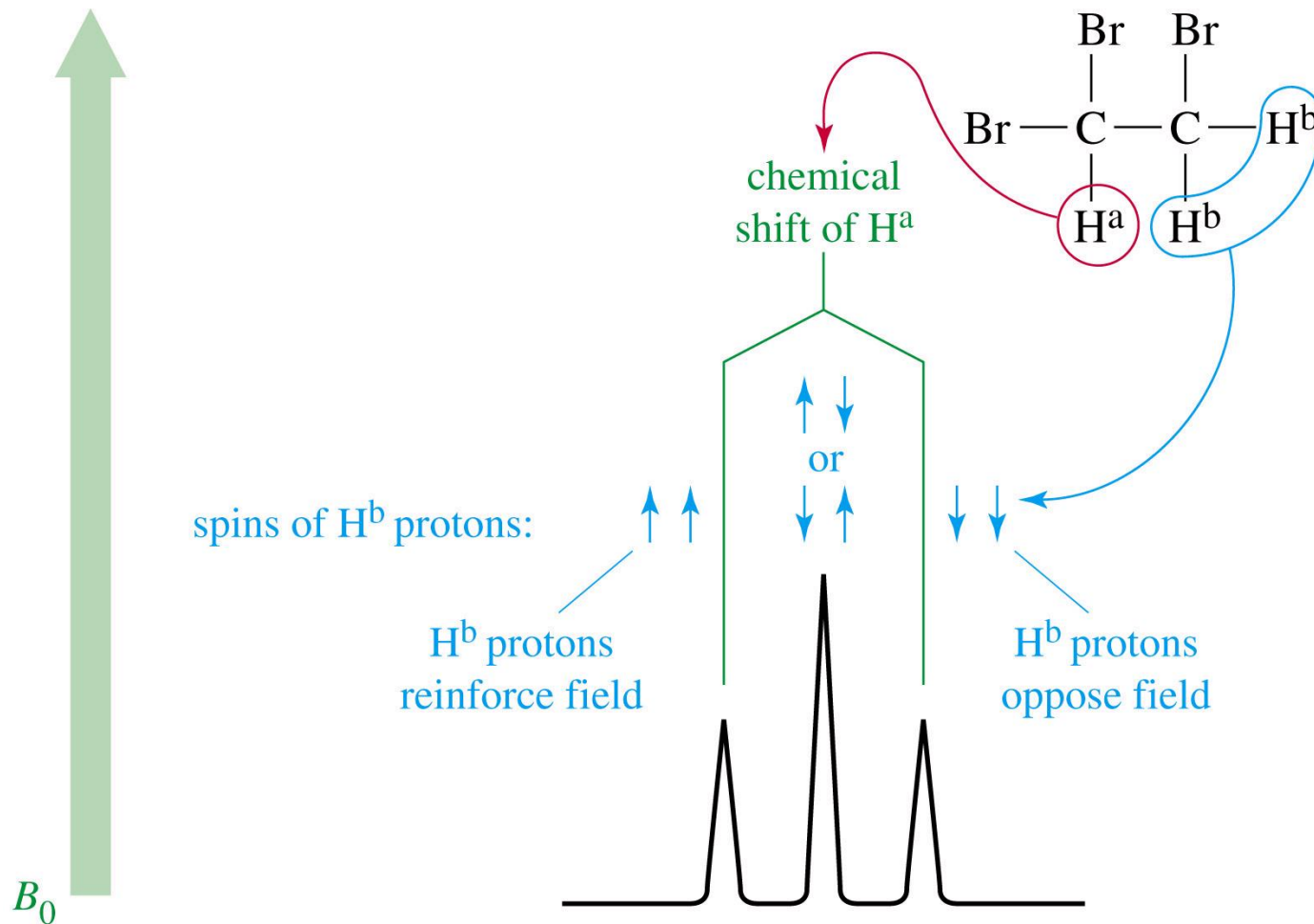


H_a is coupled to H_b and H_b

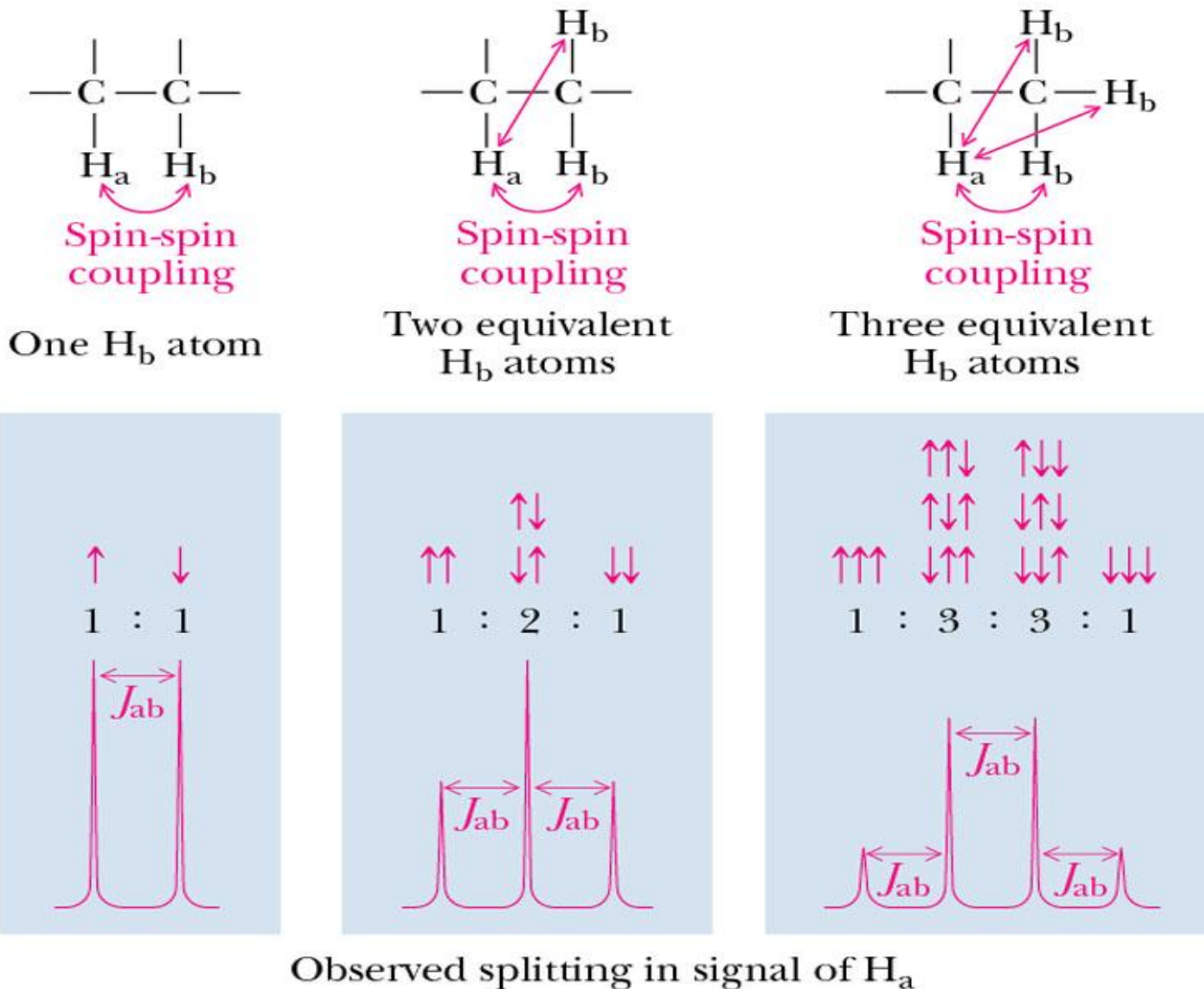
H_b can both be parallel, anti-parallel
or one parallel and one anti-parallel

∴ H_a splits into a 1:2:1 **triplet** peak

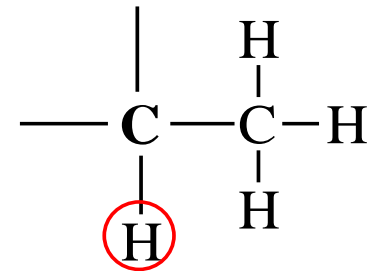
H_a in 1,1,2-Tribromoethane



Origins of Signal Splitting

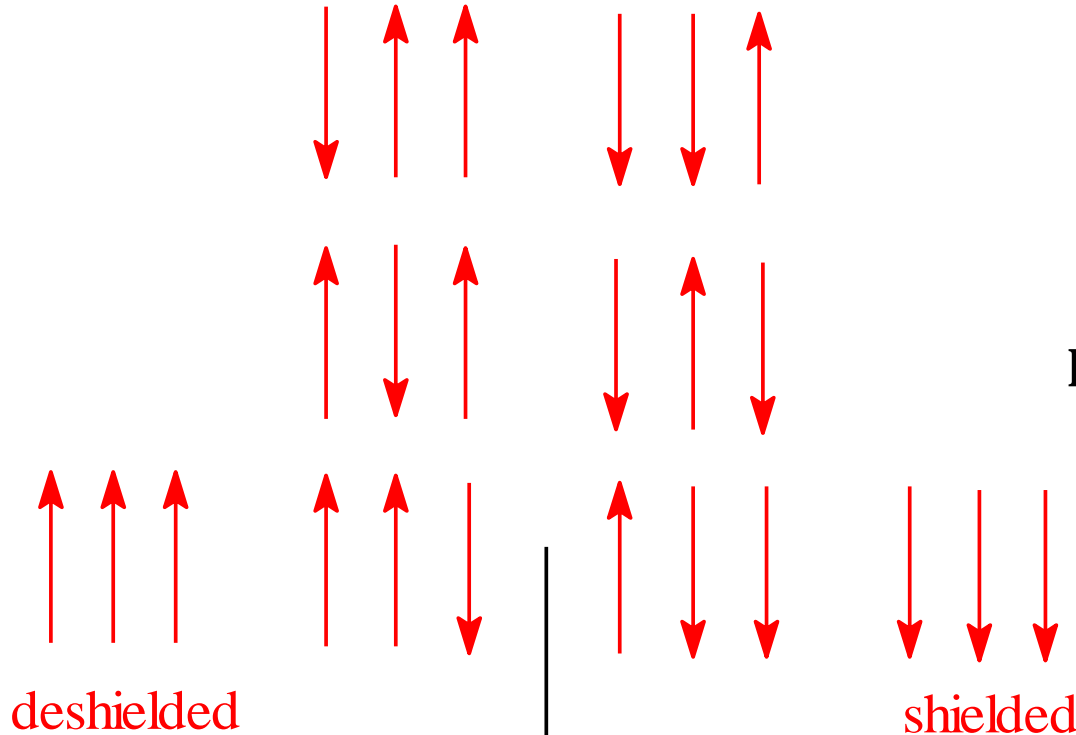


The Quartet in ^1HMR

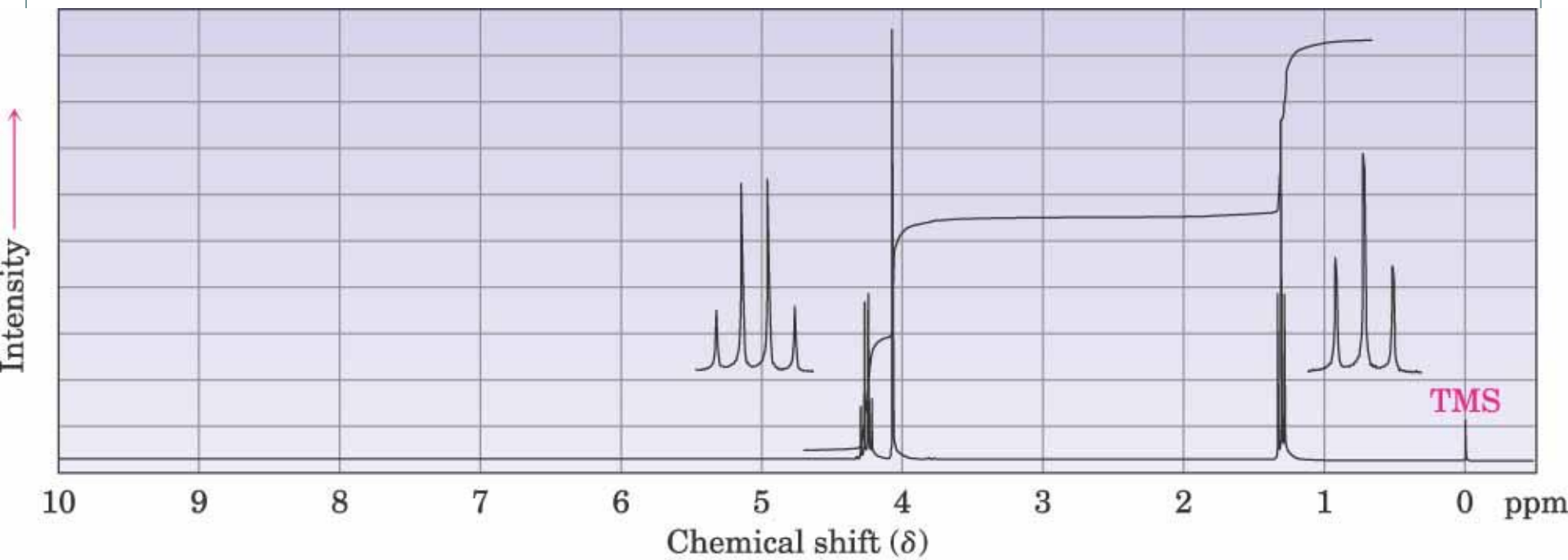


proton splits into $n+1$
quartet **1:3:3:1**
 $n = \#$ adjacent H's

B_0

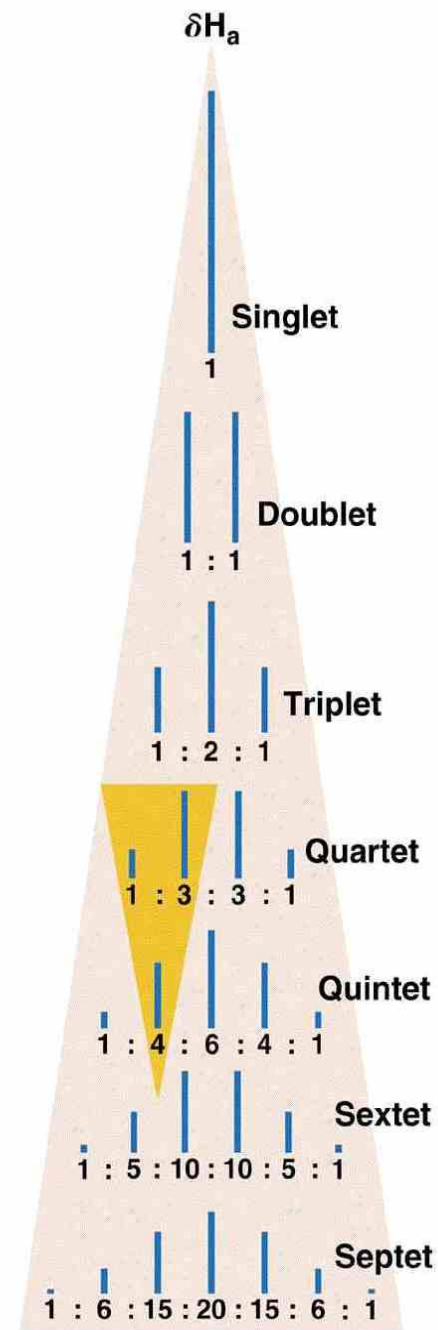


Chemical Shift



SIGNAL SPLITTING

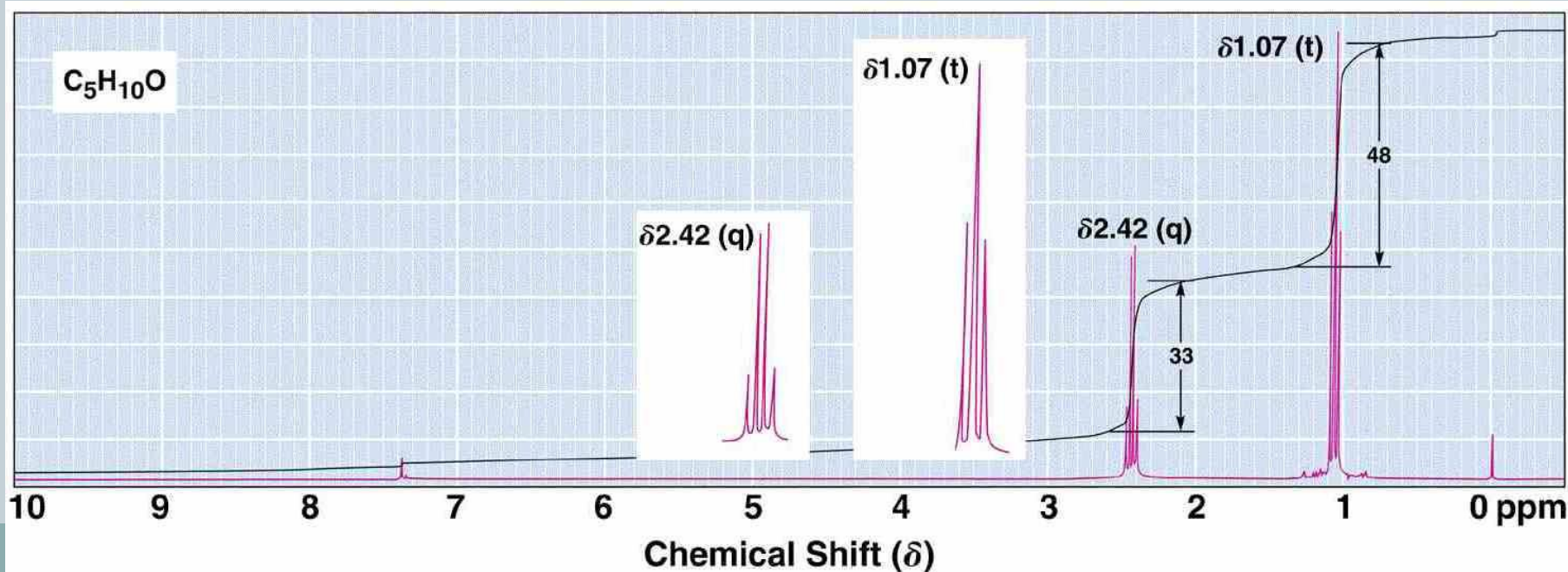
- Pascal's Triangle
 - as illustrated by the highlighted entries, each entry is the sum of the values immediately above it to the left and the right



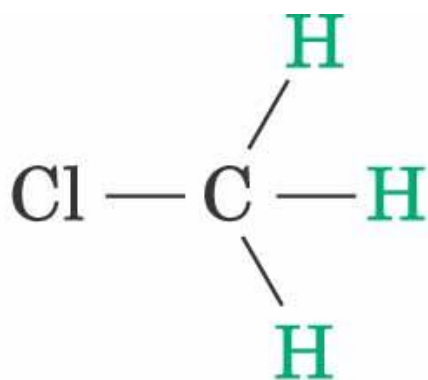
Origins of Signal Splitting



- because splitting patterns from spectra taken at 300 MHz and higher are often difficult to see, it is common to retrace certain signals in expanded form
- ^1H -NMR spectrum of 3-pentanone; scale expansion shows the triplet quartet pattern more clearly

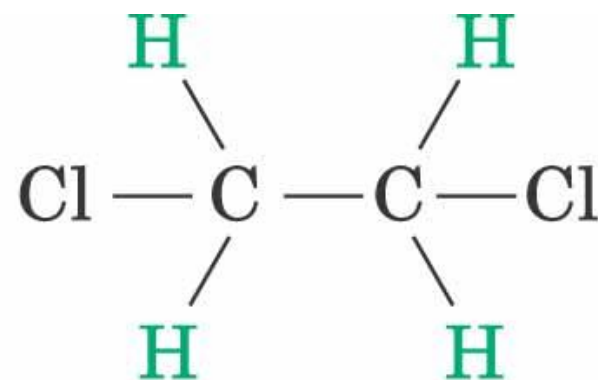


Equivalent Protons do not Couple



Three C–H protons are chemically equivalent; no splitting occurs.

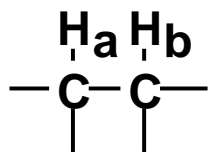
©2004 Thomson - Brooks/Cole



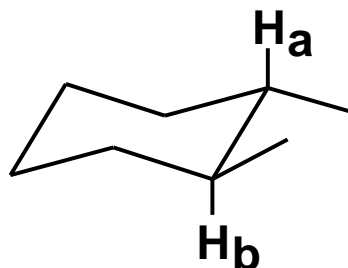
Four C–H protons are chemically equivalent; no splitting occurs.

COUPLING CONSTANTS

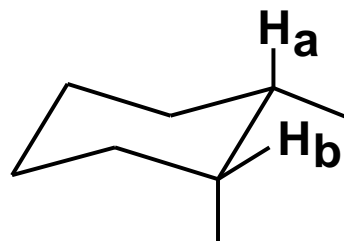
- **Coupling constant (J):** the distance between peaks in a split signal, expressed in hertz
 - the value is a quantitative measure of the magnetic interaction of nuclei whose spins are coupled



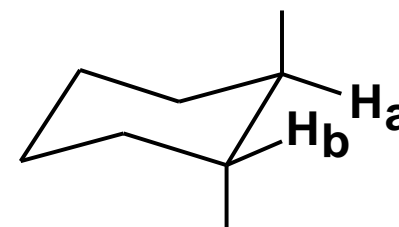
6-8 Hz



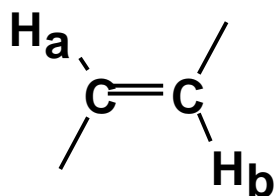
8-14 Hz



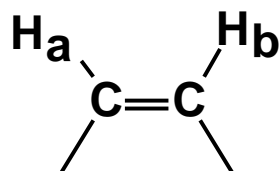
0-5 Hz



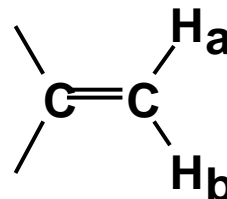
0-5 Hz



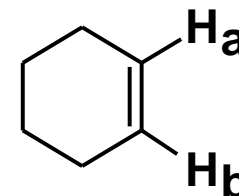
11-18 Hz



5-10 Hz



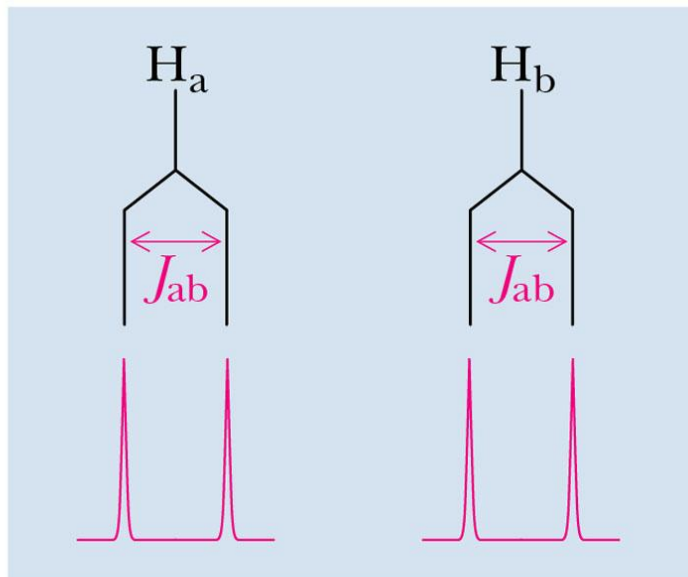
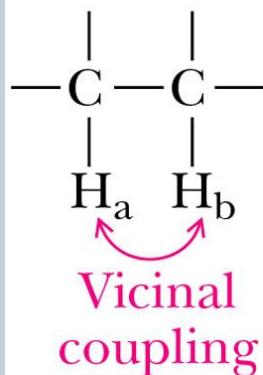
0-5 Hz



8-11 Hz

Physical Basis for $(n + 1)$ Rule

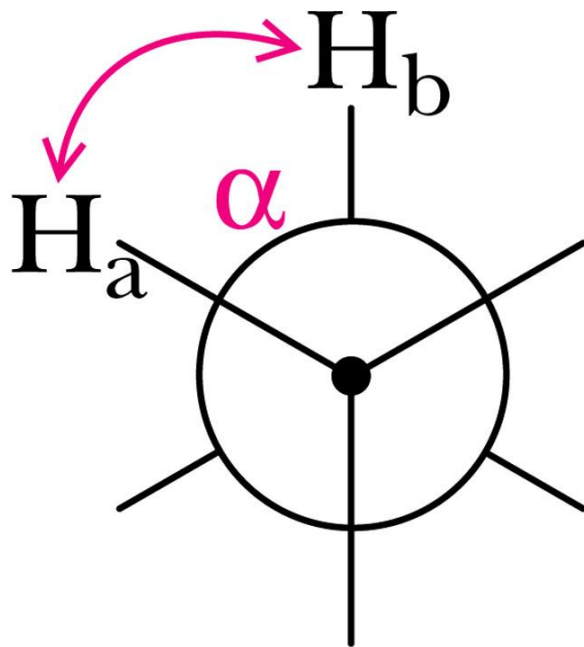
- Coupling of nuclear spins is mediated through intervening bonds
 - H atoms with more than three bonds between them generally do not exhibit noticeable coupling
 - for H atoms three bonds apart, the coupling is referred to as vicinal coupling



Coupling Constants



- an important factor in vicinal coupling is the angle α between the C-H sigma bonds and whether or not it is fixed
- coupling is a maximum when α is 0° and 180° ; it is a minimum when α is 90°



MECHANISM OF COUPLING – THREE BOND COUPLINGS, 3J

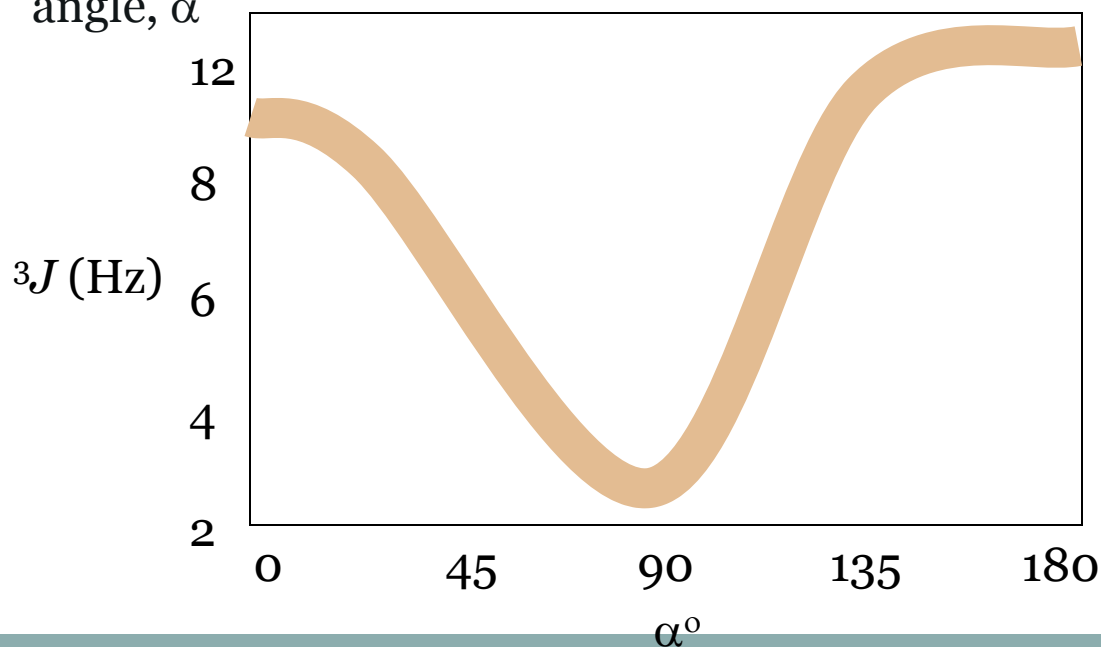


This observation was quantified by Martin Karplus, who determined that the experimental data best fit the following equation:

$${}^3J_{HH} = A + B \cos \alpha + C \cos 2\alpha$$

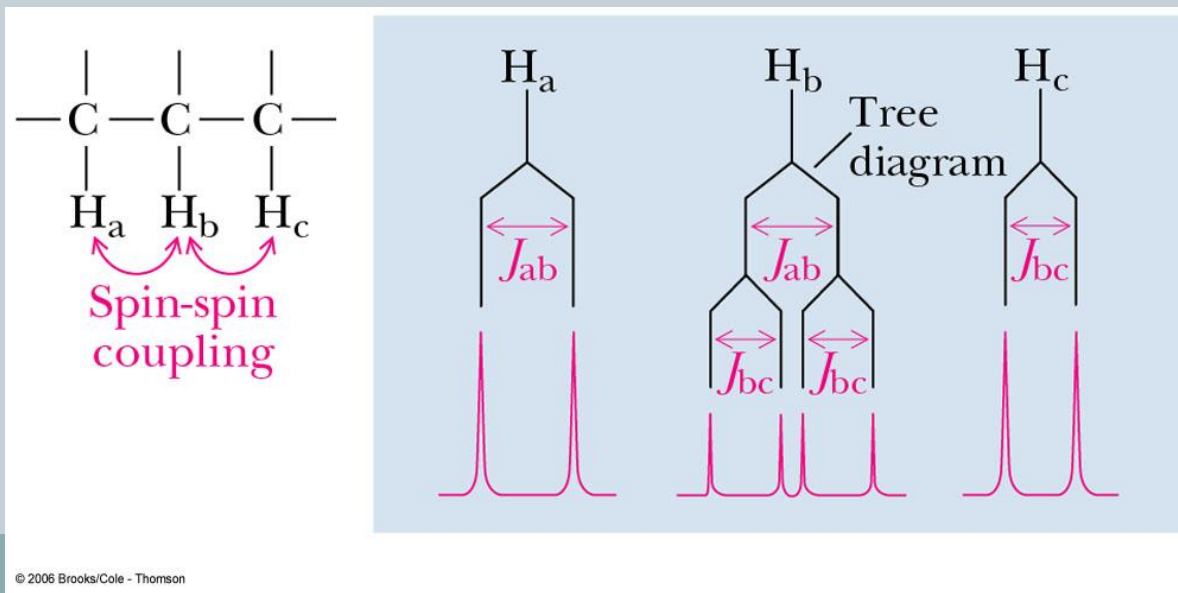
Where A , B , and C are empirically determined constants

This observation showed the variation of coupling constant with dihedral angle, α



More Complex Splitting Patterns

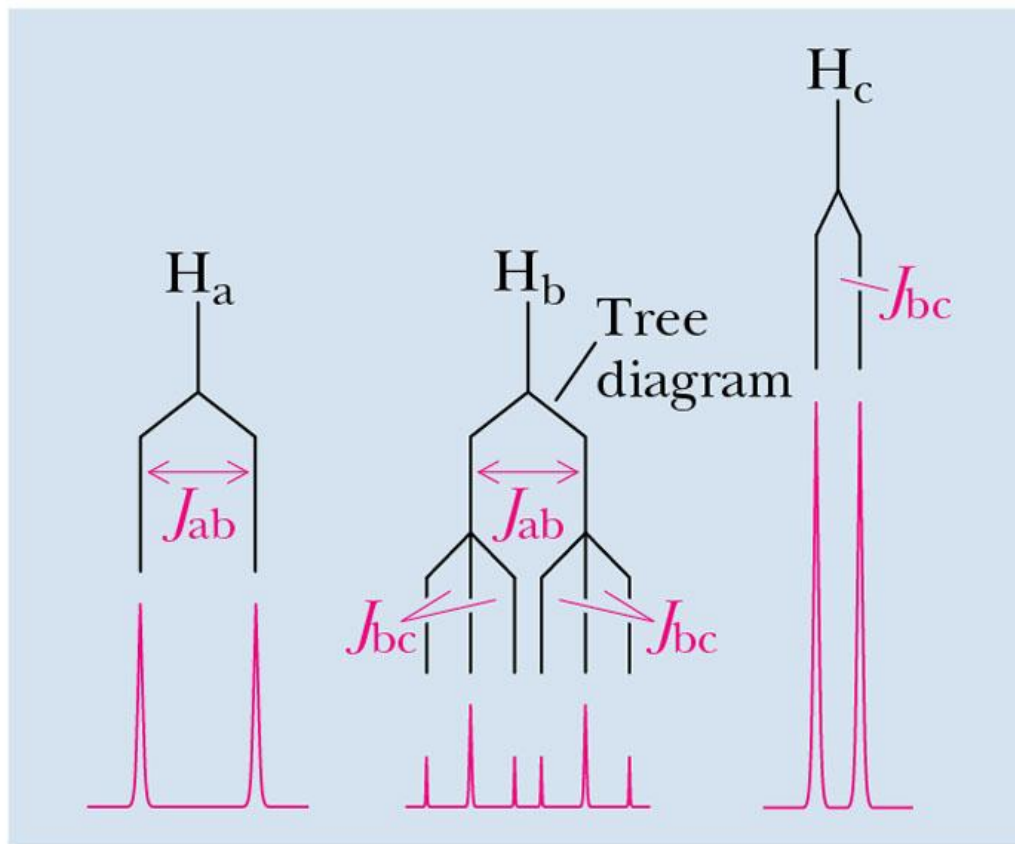
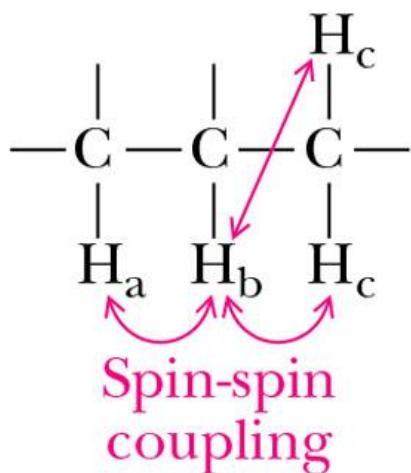
- thus far, we have concentrated on spin-spin coupling with only one other nonequivalent set of H atoms
- more complex splittings arise when a set of H atoms couples to more than one set H atoms
- a tree diagram shows that when H_b is adjacent to nonequivalent H_a on one side and H_c on the other, the resulting coupling gives rise to a doublet of doublets



More Complex Splitting Patterns



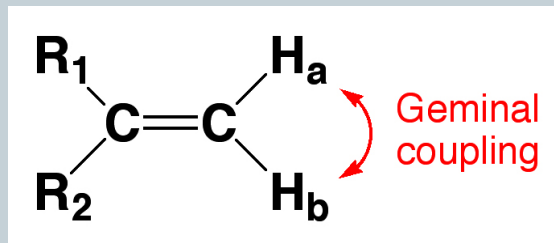
- if H_c is a set of two equivalent H, then the observed splitting is a doublet of triplets



More Complex Splitting Patterns



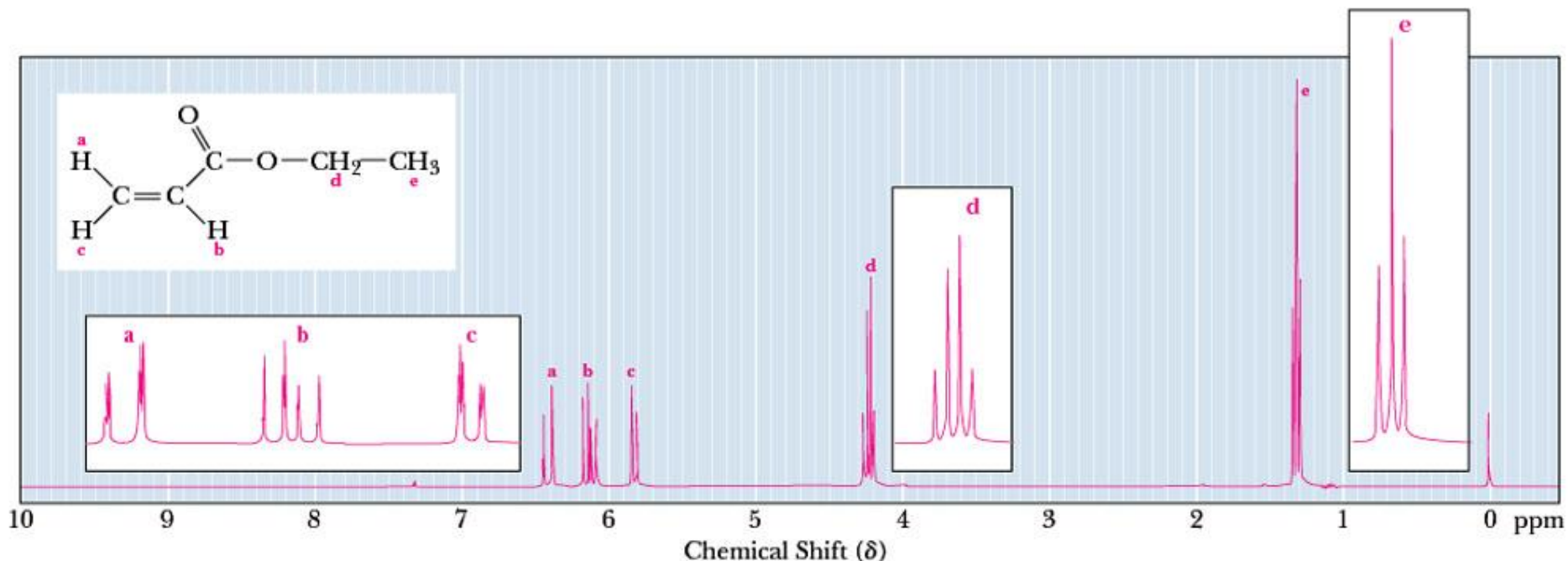
- because the angle between C-H bond determines the extent of coupling, bond rotation is a key parameter
- in molecules with relatively free rotation about C-C sigma bonds, H atoms bonded to the same carbon in CH₃ and CH₂ groups generally are equivalent
- if there is restricted rotation, as in alkenes and cyclic structures, H atoms bonded to the same carbon may not be equivalent
- nonequivalent H on the same carbon will couple and cause signal splitting
- this type of coupling is called geminal coupling



More Complex Splitting Patterns

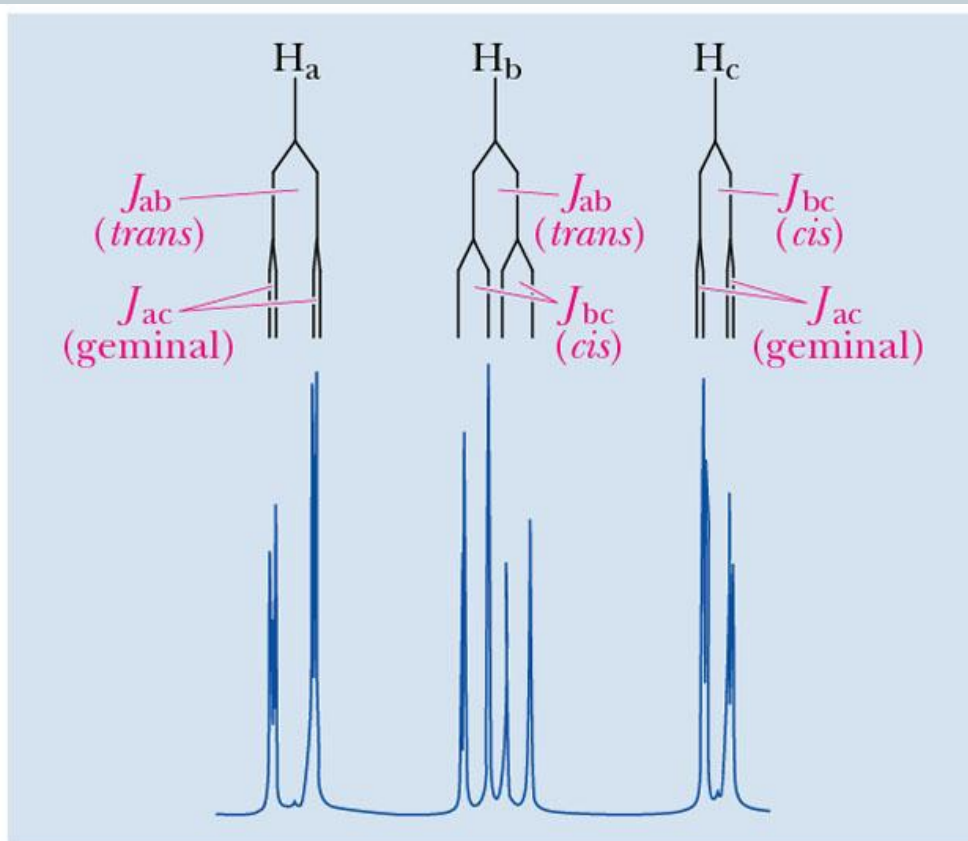
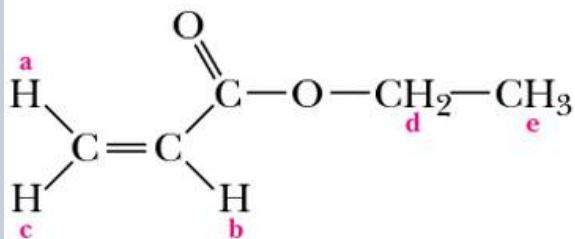


- in ethyl propenoate, an unsymmetrical terminal alkene, the three vinylic hydrogens are nonequivalent



More Complex Splitting Patterns

- a tree diagram for the complex coupling of the three vinylic hydrogens in ethyl propenoate



More Complex Splitting Patterns

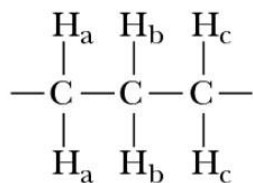


- Complex coupling in flexible molecules
 - coupling in molecules with unrestricted bond rotation often gives only $m + n + 1$ peaks
 - that is, the number of peaks for a signal is the number of adjacent hydrogens + 1, no matter how many different sets of equivalent H atoms that represents
 - the explanation is that bond rotation averages the coupling constants throughout molecules with freely rotation bonds and tends to make them similar; for example in the 6- to 8-Hz range for H atoms on freely rotating sp^3 hybridized C atoms

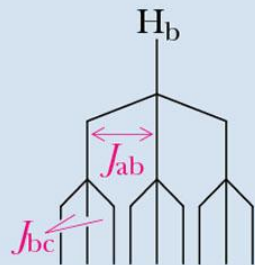
More Complex Splitting Patterns



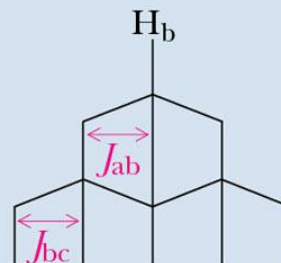
- simplification of signal splitting occurs when coupling constants are the same



J_{ab} and J_{bc} are not equal



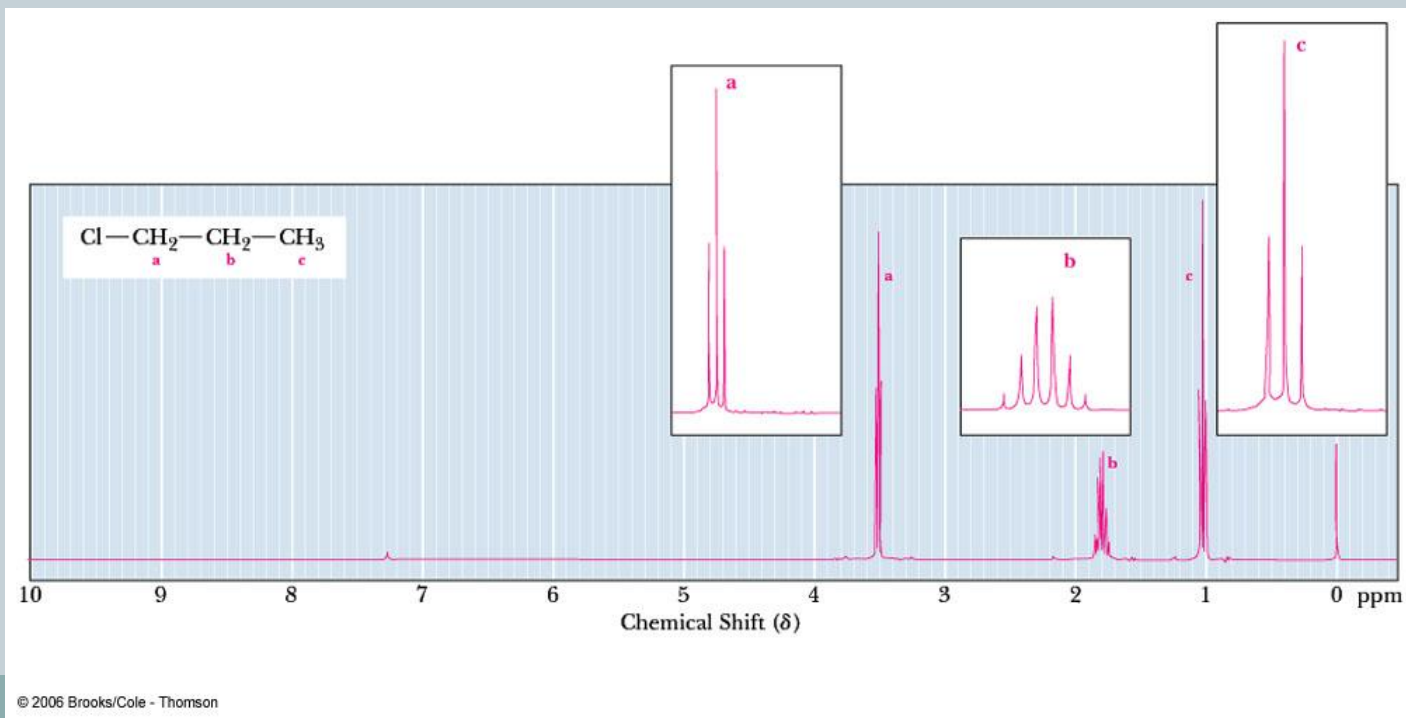
J_{ab} and J_{bc} are equal



More Complex Splitting Patterns



- an example of peak overlap occurs in the spectrum of 1-chloro-3-iodopropane
- the central CH_2 has the possibility for 9 peaks (a triplet of triplets) but because J_{ab} and J_{bc} are so similar, only $4 + 1 = 5$ peaks are distinguishable



STEREOCHEMISTRY & TOPICITY

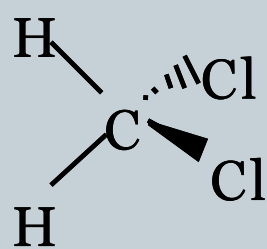


- Depending on the symmetry of a molecule, otherwise equivalent hydrogens may be
 - homotopic
 - enantiotopic
 - diastereotopic
- The simplest way to visualize topicity is to substitute an atom or group by an isotope; is the resulting compound
 - the same as its mirror image
 - different from its mirror image
 - are diastereomers possible

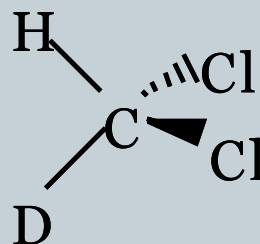
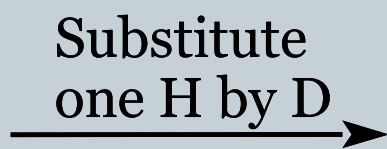
Stereochemistry & Topicity



- Homotopic atoms or groups



Dichloro-
methane
(achiral)



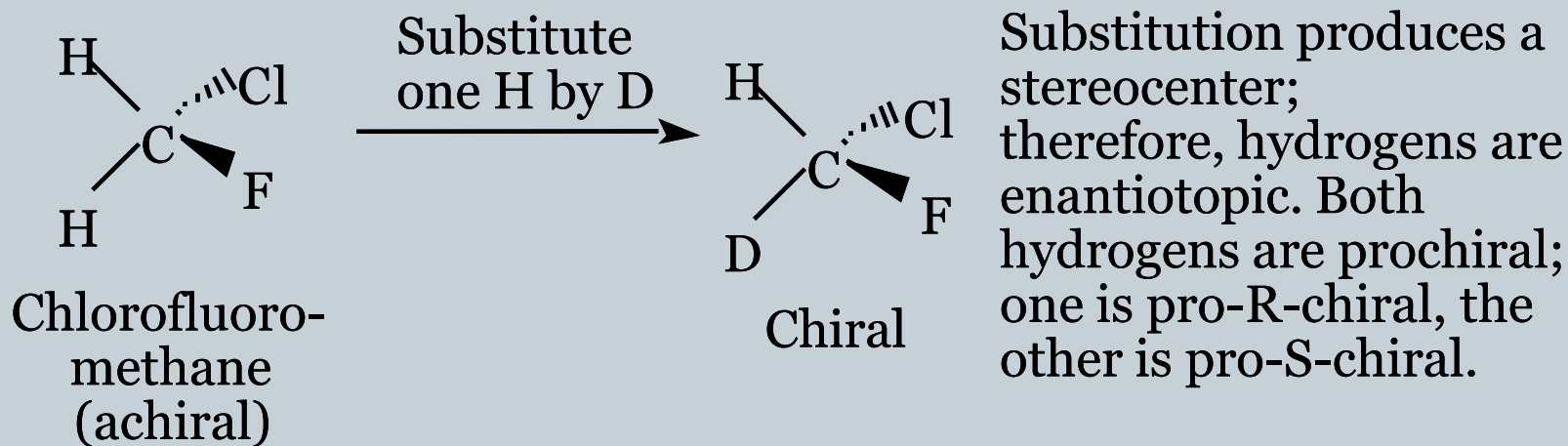
Achiral

Substitution does not
produce a stereocenter;
therefore hydrogens
are homotopic.

- homotopic atoms or groups have identical chemical shifts under all conditions

Stereochemistry & Topicity

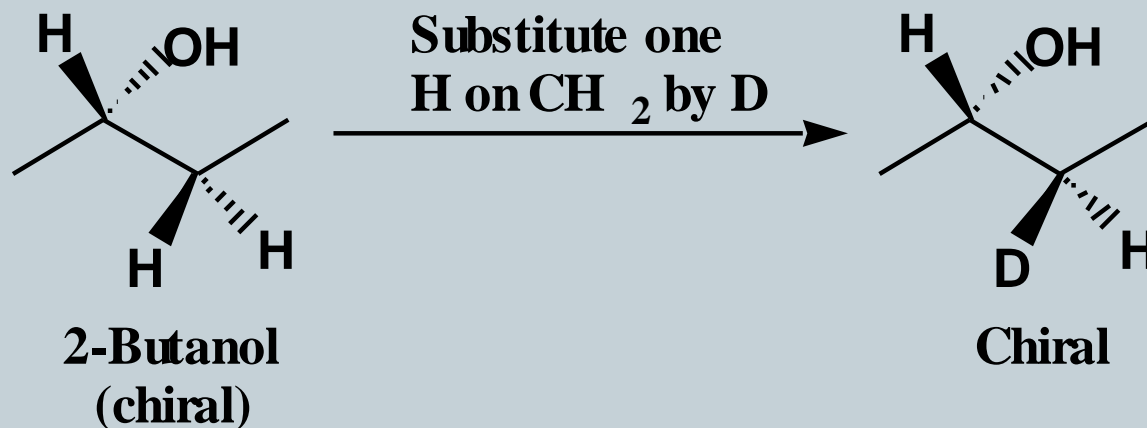
- Enantiotopic groups



- enantiotopic atoms or groups have identical chemical shifts in achiral environments
- they have different chemical shifts in chiral environments

Stereochemistry & Topicity

- Diastereotopic groups
 - H atoms on C-3 of 2-butanol are diastereotopic
 - substitution by deuterium creates a chiral center
 - because there is already a chiral center in the molecule, diastereomers are now possible

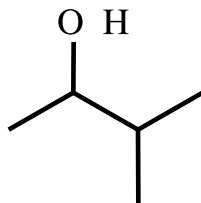


- diastereotopic hydrogens have different chemical shifts under all conditions

Stereochemistry & Topicity



- The methyl groups on carbon 3 of 3-methyl-2-butanol are diastereotopic
 - if a methyl hydrogen of carbon 4 is substituted by deuterium, a new chiral center is created
 - because there is already one chiral center, diastereomers are now possible

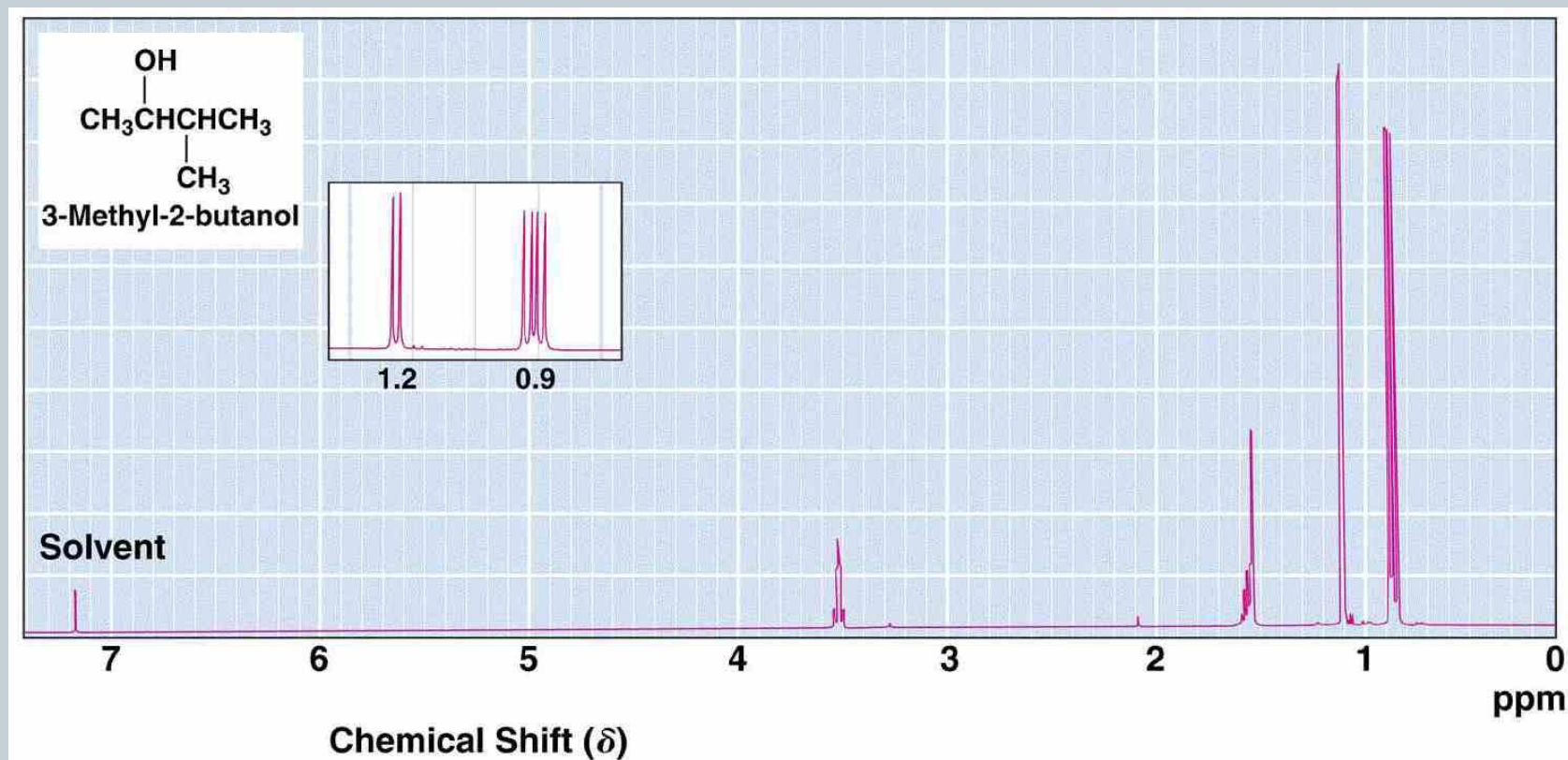


3-Methyl-2-butanol

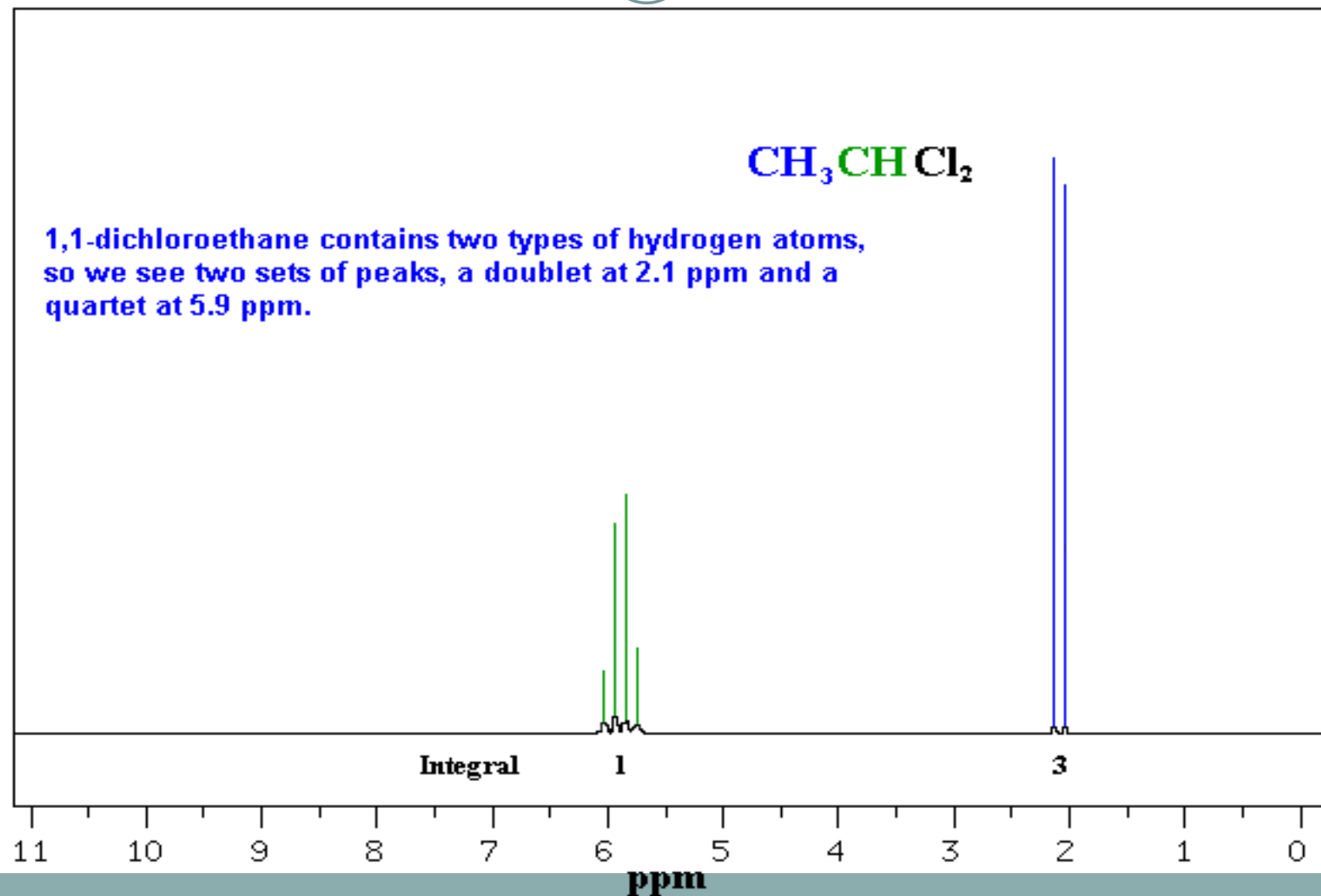
- protons of the methyl groups on carbon 3 have different chemical shifts

Stereochemistry and Topicity

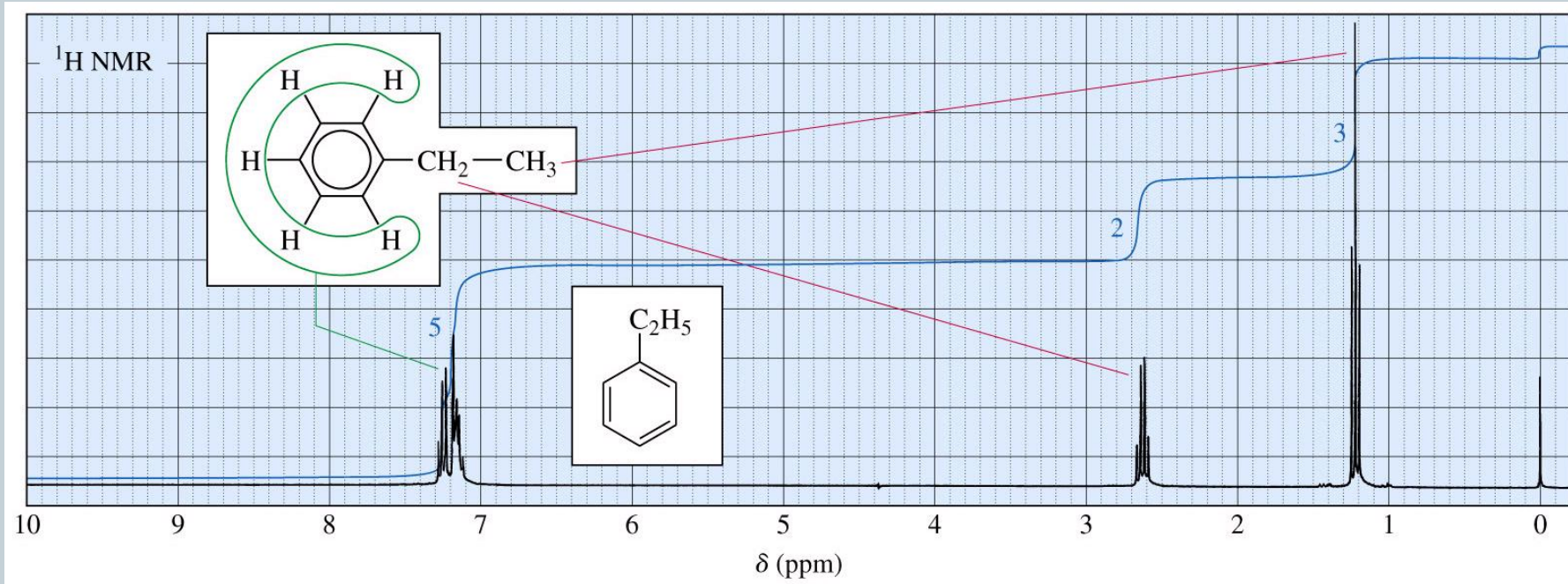
- $^1\text{H-NMR}$ spectrum of 3-methyl-2-butanol
 - the methyl groups on carbon 3 are diastereotopic and appear as two doublets



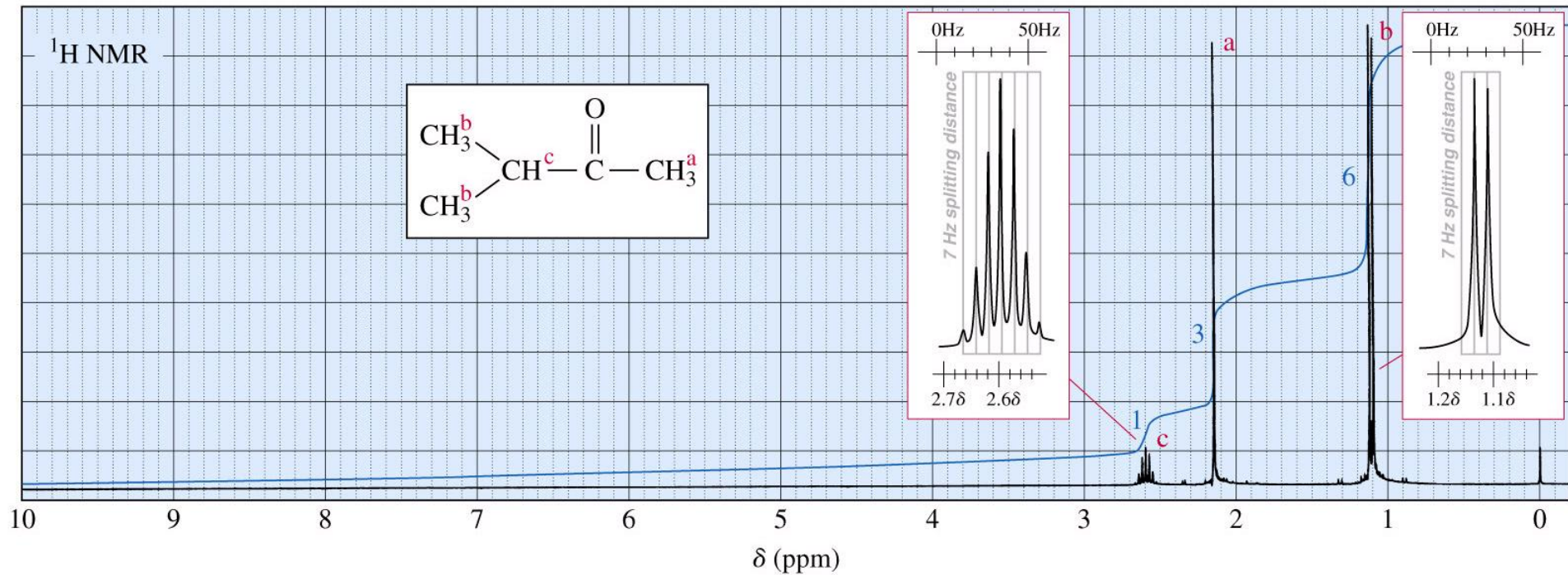
1,1-Dichloroethane



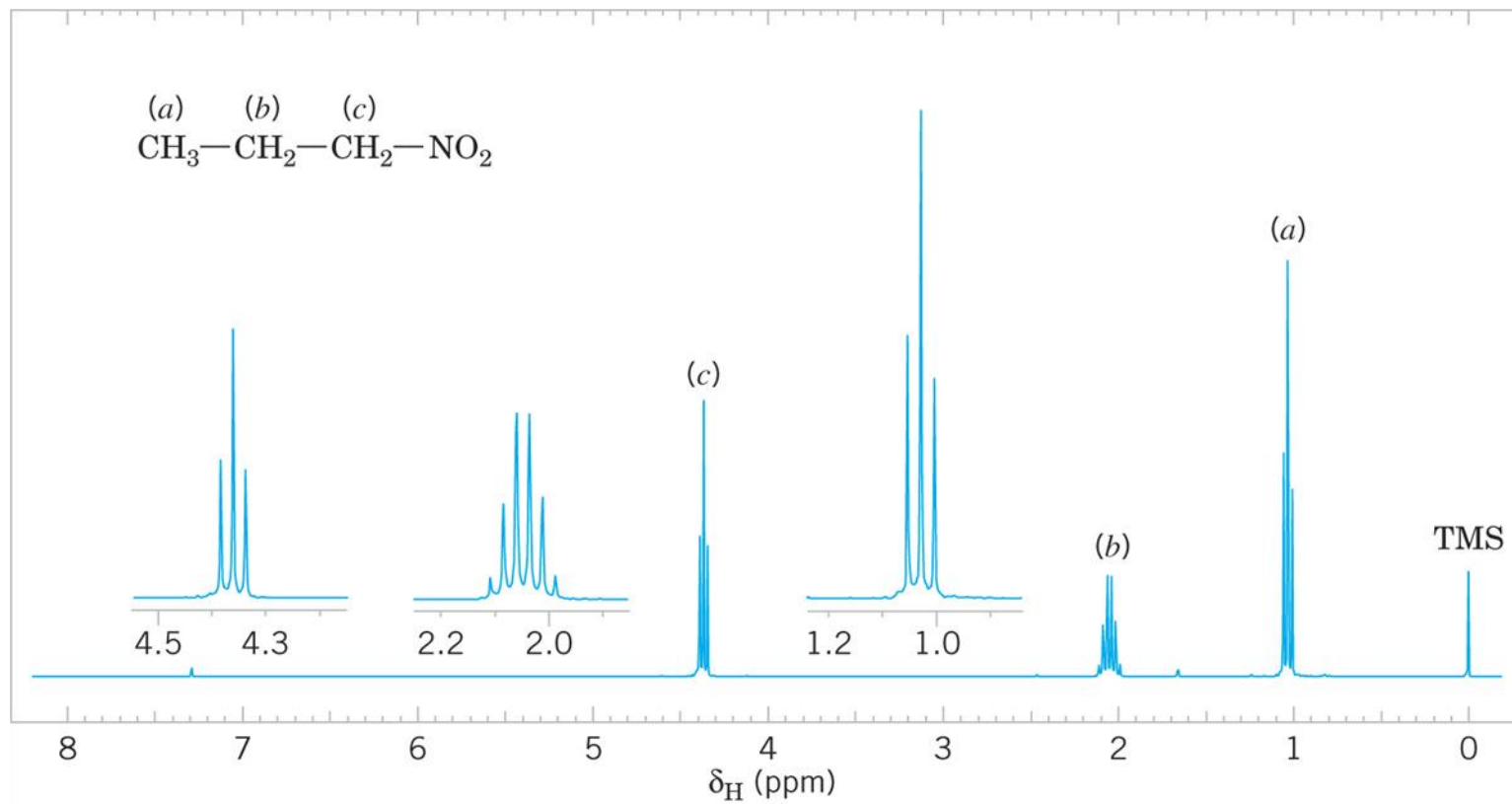
Ethyl benzene



Methyl Isopropyl Ketone



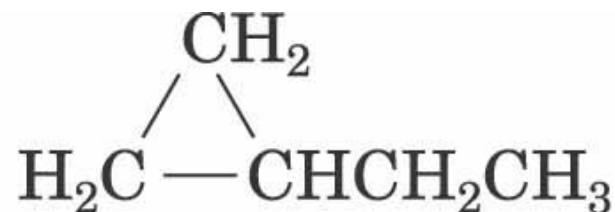
1-Nitropropane



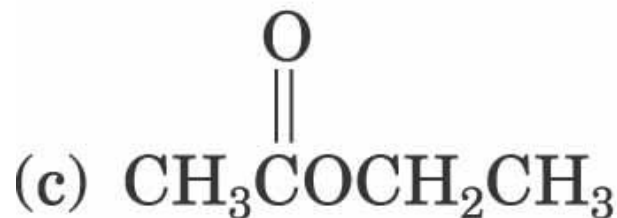
Differentiate using ^1H NMR



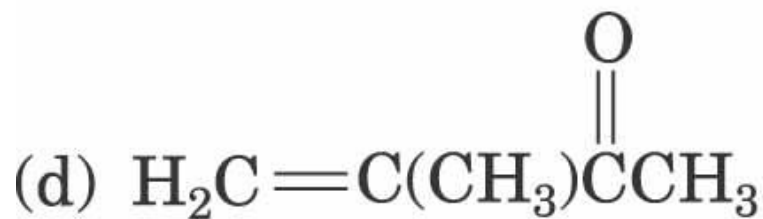
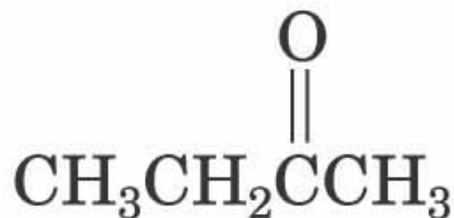
and



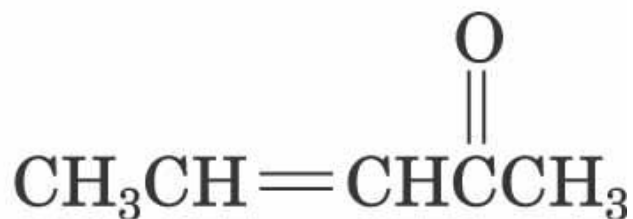
and



and

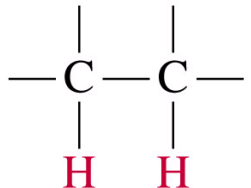
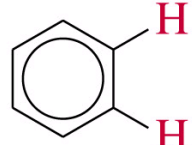
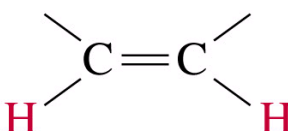
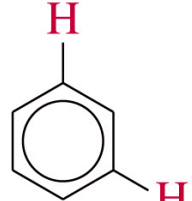
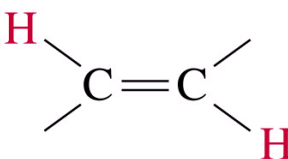
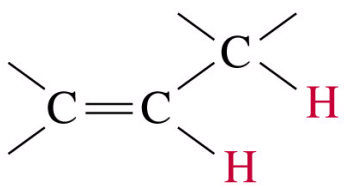
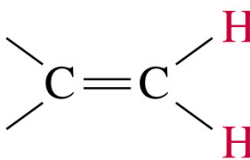


and



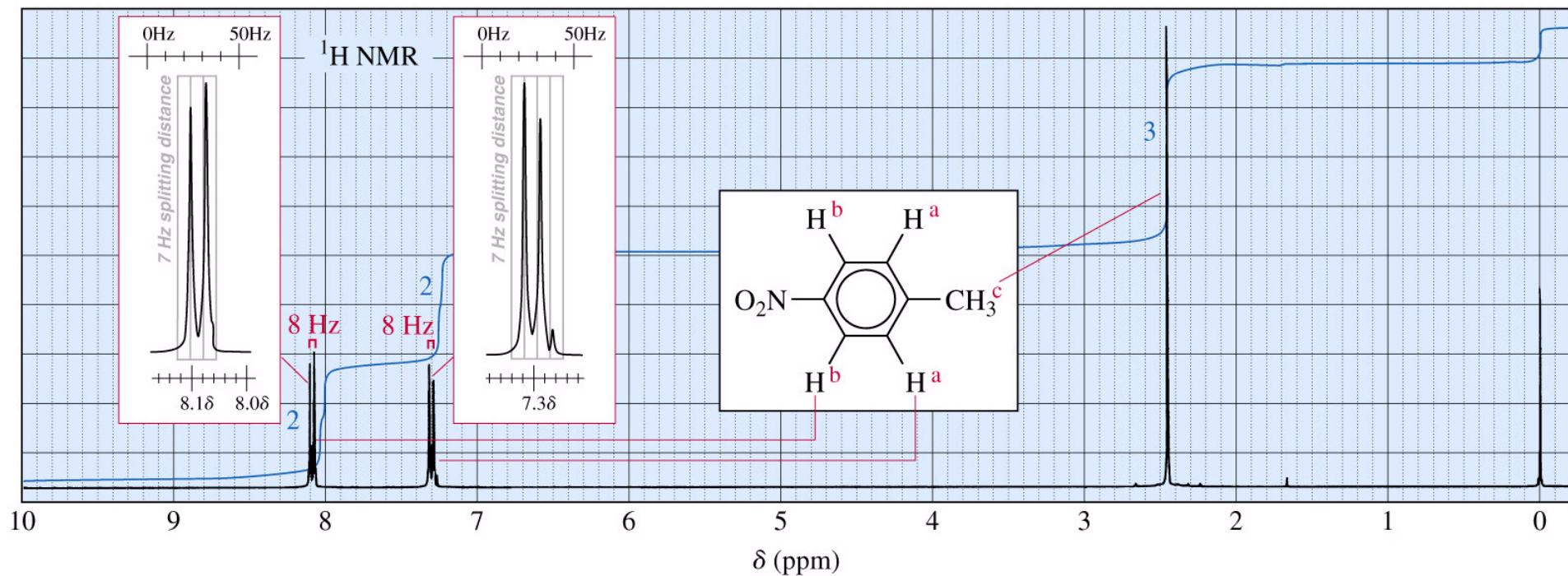
Coupling Constants (J values)



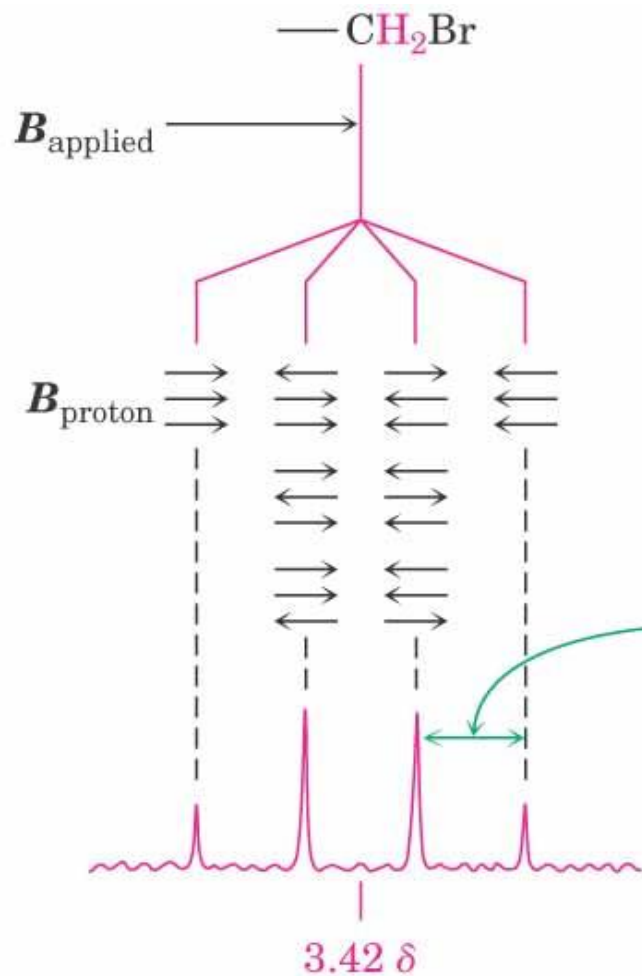
	<u>Approx. J</u>		<u>Approx. J</u>
 (free rotation)	7 Hz ^a	 (ortho)	8 Hz
 (cis)	10 Hz	 (meta)	2 Hz
 (trans)	15 Hz	 (allylic)	6 Hz
 (geminal)	2 Hz		

^aThe value of 7 Hz in an alkyl group is averaged for rapid rotation about the carbon–carbon bond. If rotation is hindered by a ring or bulky groups, other splitting constants may be observed.

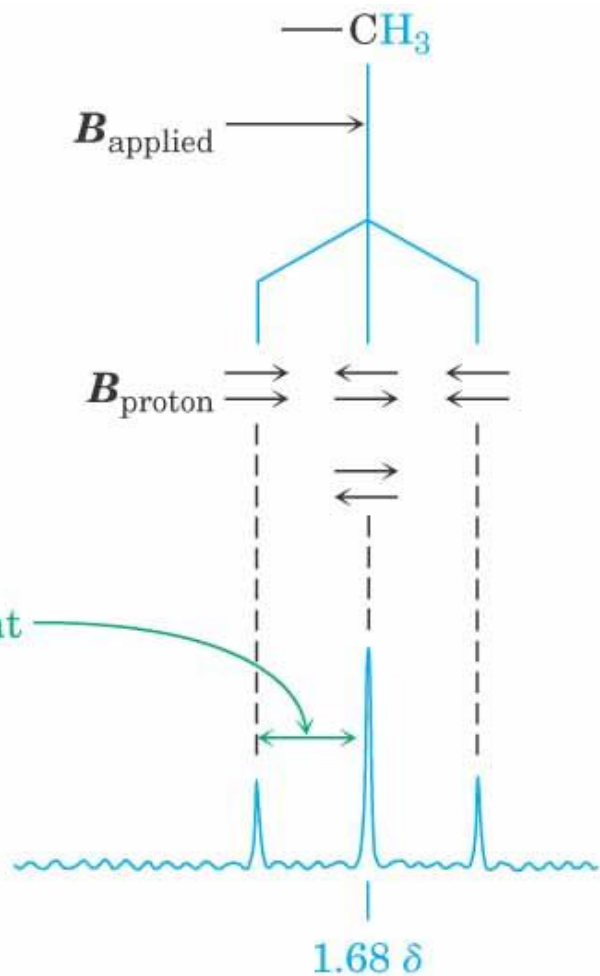
Para Nitrotoluene



Bromoethane

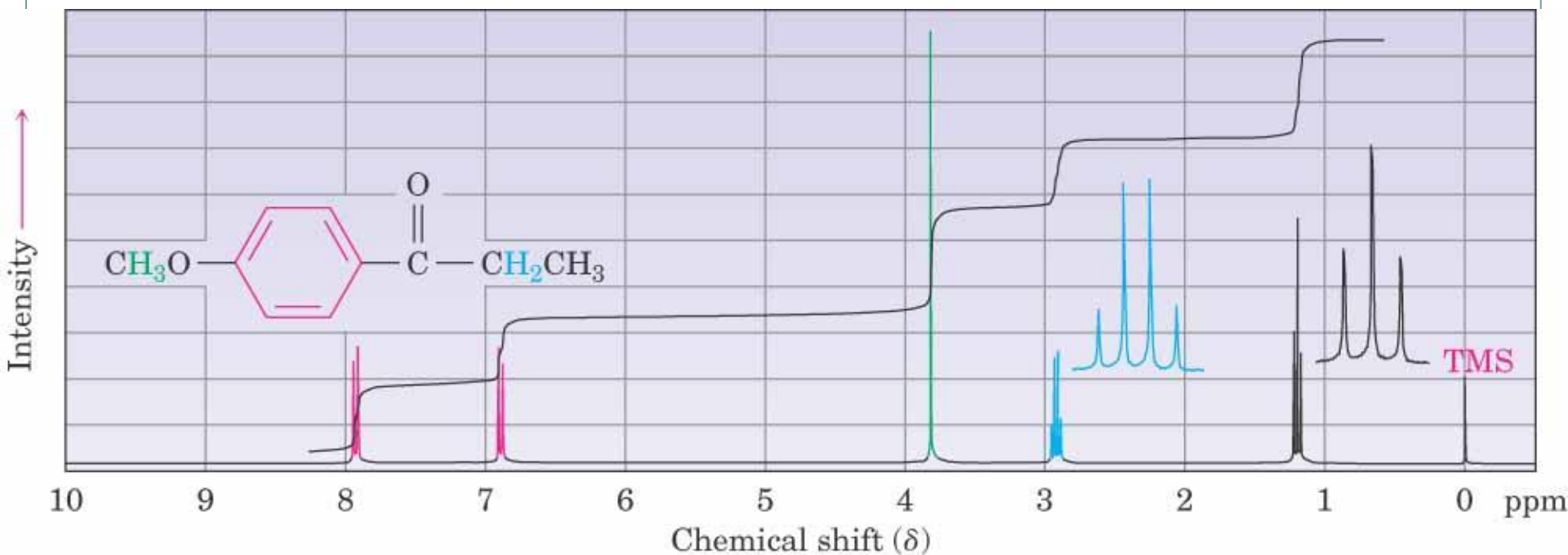


Quartet due to coupling with —CH_3

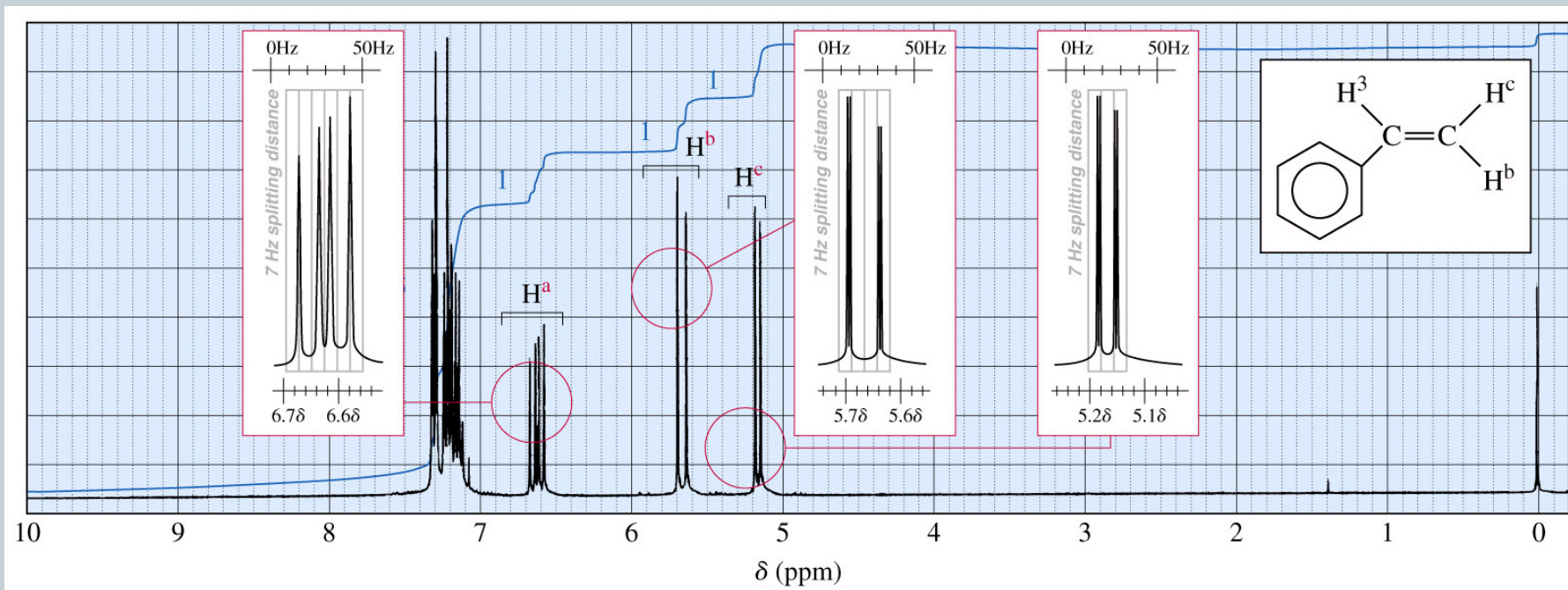


Triplet due to coupling with $\text{—CH}_2\text{Br}$

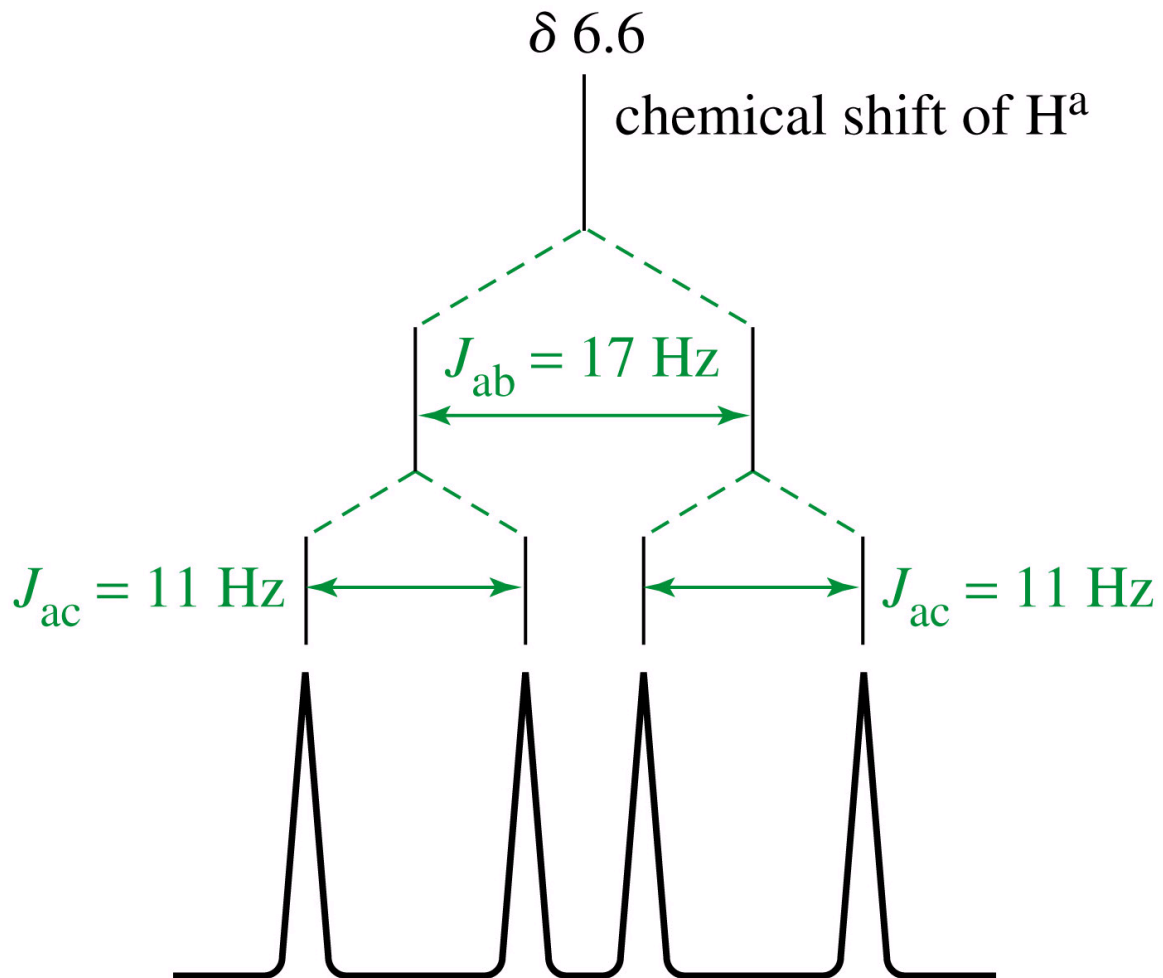
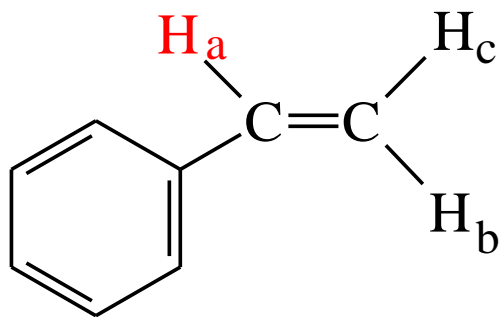
para-Methoxypropiophenone



Styrene

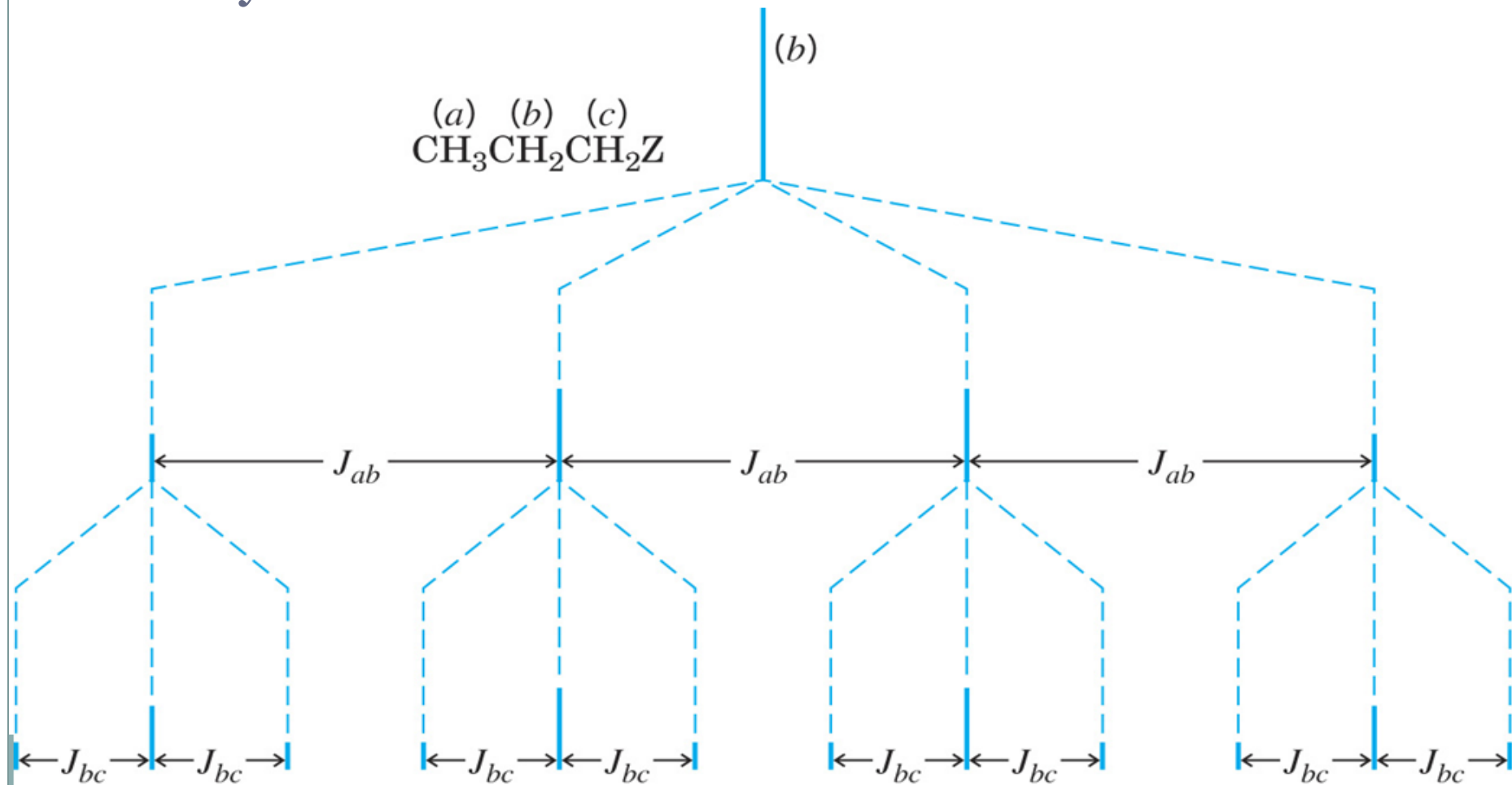


H_a splitting in Styrene “Tree” Diagram



In the system below, H_b is split by two different sets of hydrogens : H_a and H_c

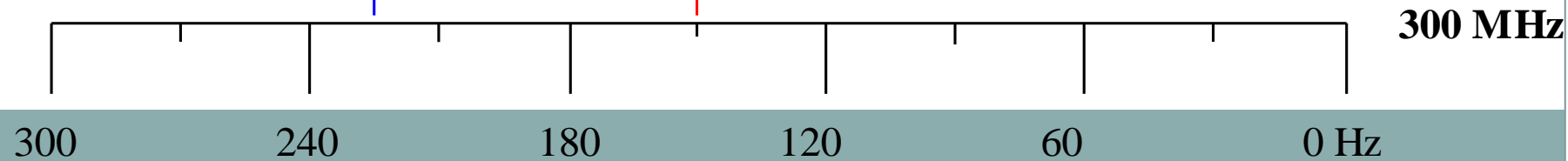
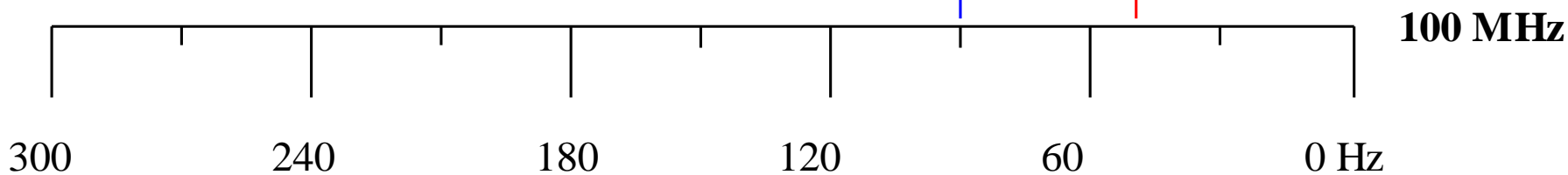
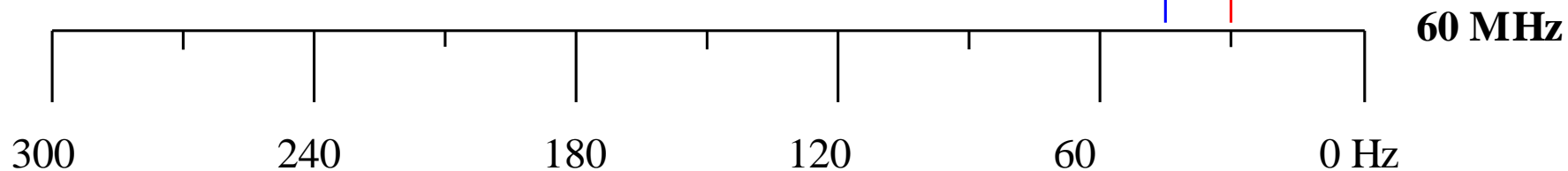
- Theoretically H_b could be split into a triplet of quartets (12 peaks) but this complexity is rarely seen in aliphatic systems



Why go to a higher field strength?

$\delta 0.50$

$\delta 0.75$



$\delta 0.50$ (t, 2H, J=10)

$\delta 0.75$ (t, 2H, J=10)

