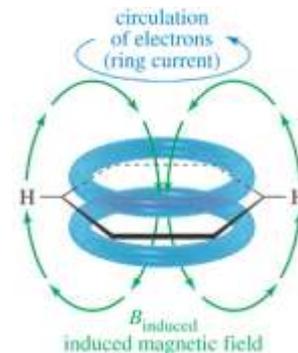


Organic Chemistry, 7th Edition
L. G. Wade, Jr.



Chapter 13

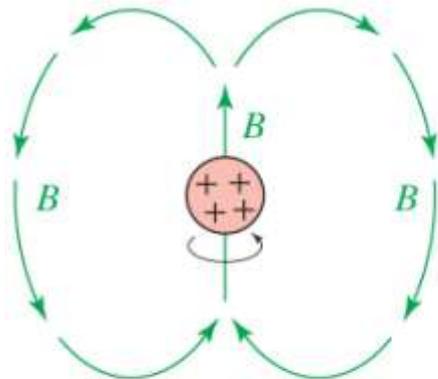
Nuclear Magnetic Resonance Spectroscopy

Introduction

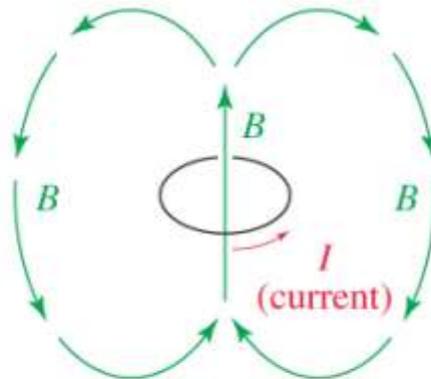
- NMR is the most powerful tool available for organic structure determination.
- It is used to study a wide variety of nuclei:
 - ^1H
 - ^{13}C
 - ^{15}N
 - ^{19}F
 - ^{31}P

Nuclear Spin

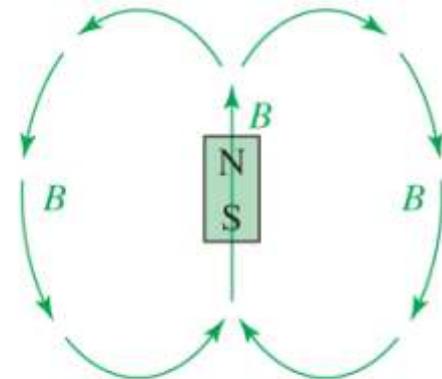
- A nucleus with an odd atomic number or an odd mass number has a nuclear spin.
- The spinning charged nucleus generates a magnetic field.



spinning proton



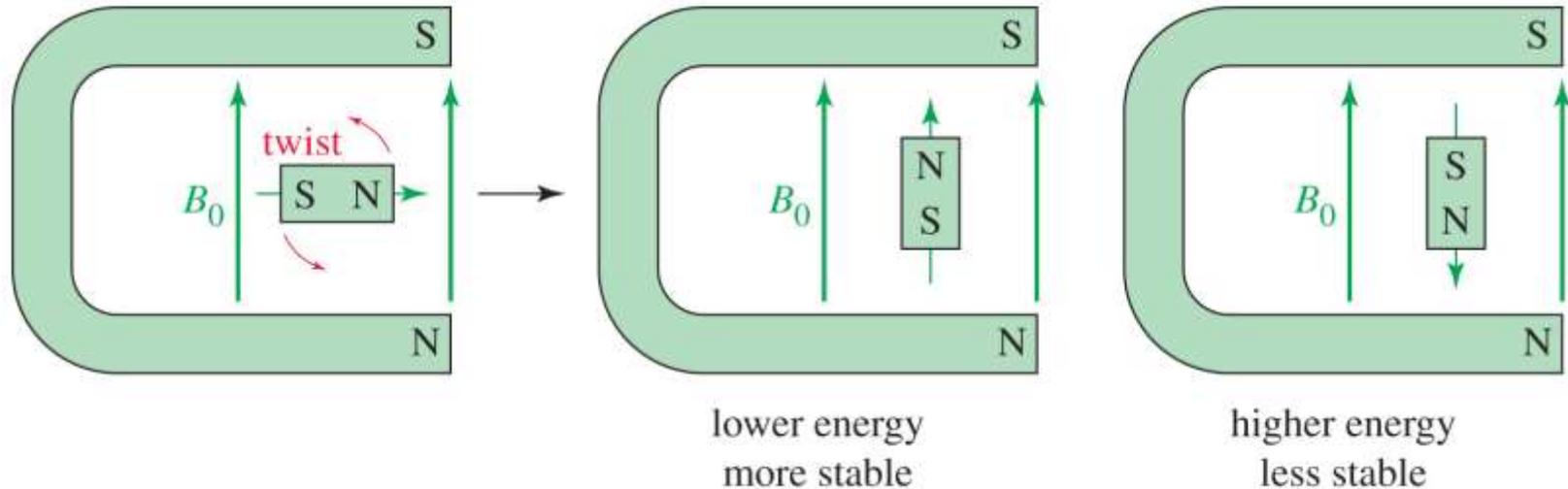
loop of current



bar magnet

Copyright © 2010 Pearson Prentice Hall, Inc.

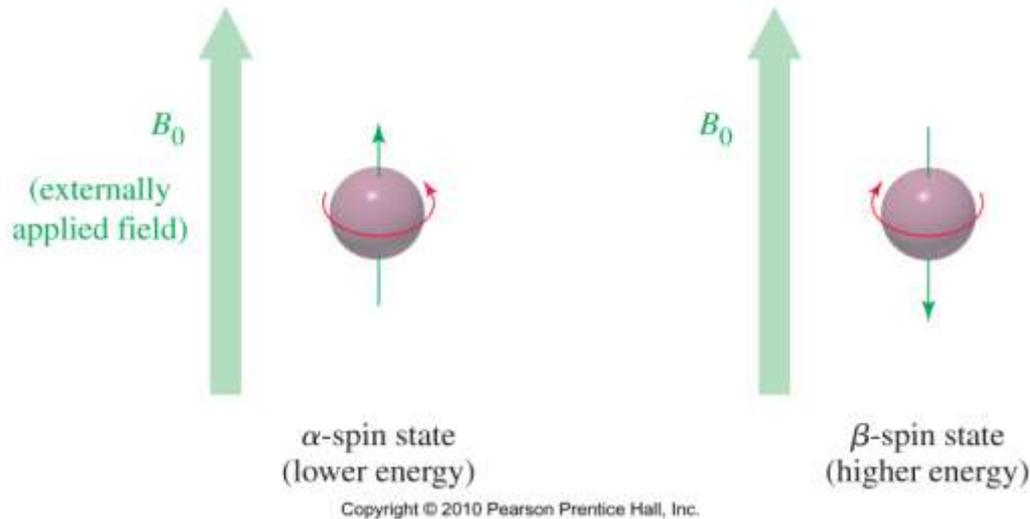
External Magnetic Field



Copyright © 2010 Pearson Prentice Hall, Inc.

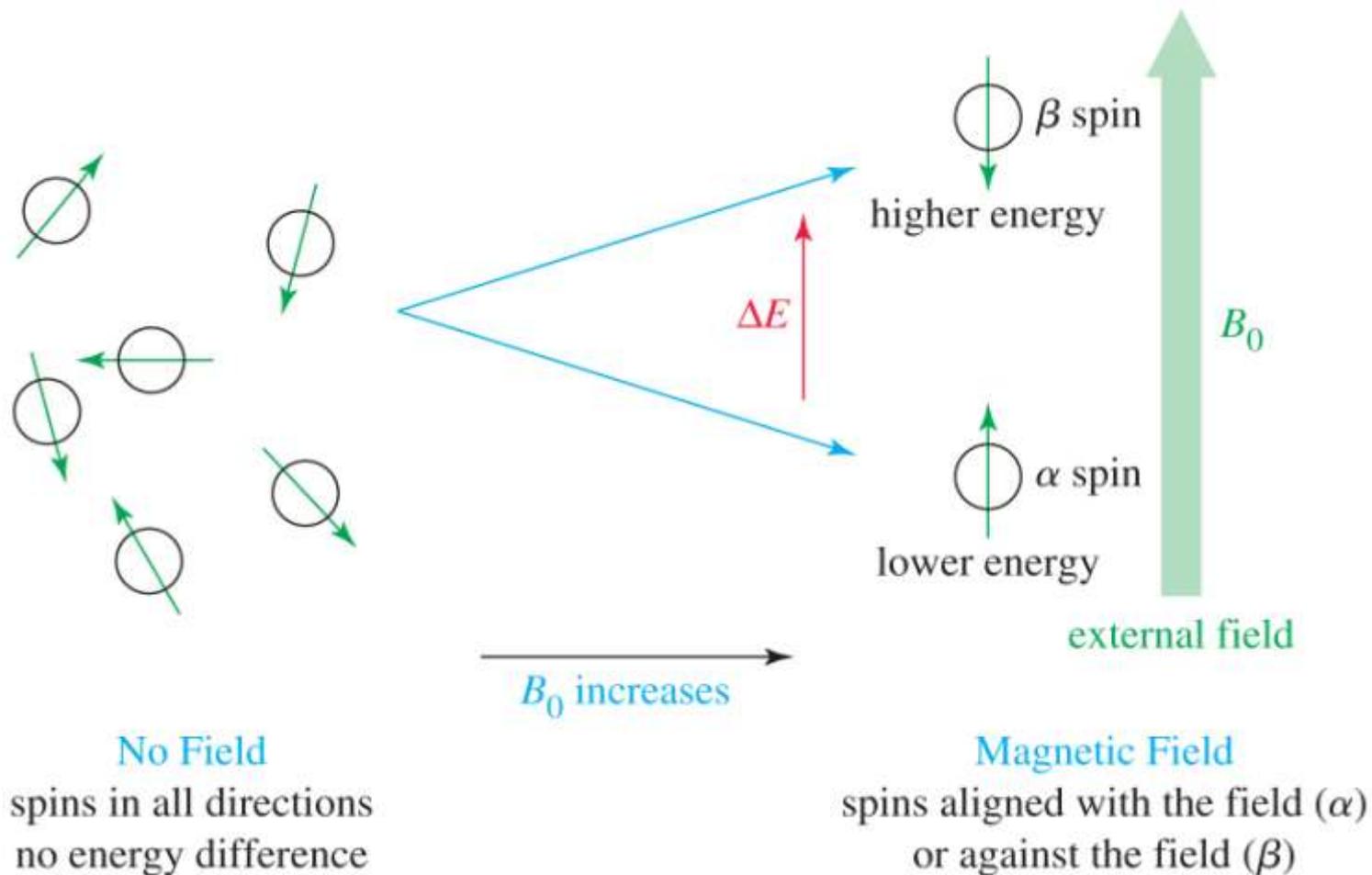
- An external magnetic field (B_0) applies a force to a small bar magnet, twisting the bar magnet to align it with the external field.
- The arrangement of the bar magnet aligned with the field is lower in energy than the arrangement aligned against the field.

Alpha-spin State and *Beta*-spin State.



- The lower energy state with the proton aligned with the field is called the *alpha-spin state*.
- The higher energy state with the proton aligned against the external magnetic field is called the *beta-spin state*.

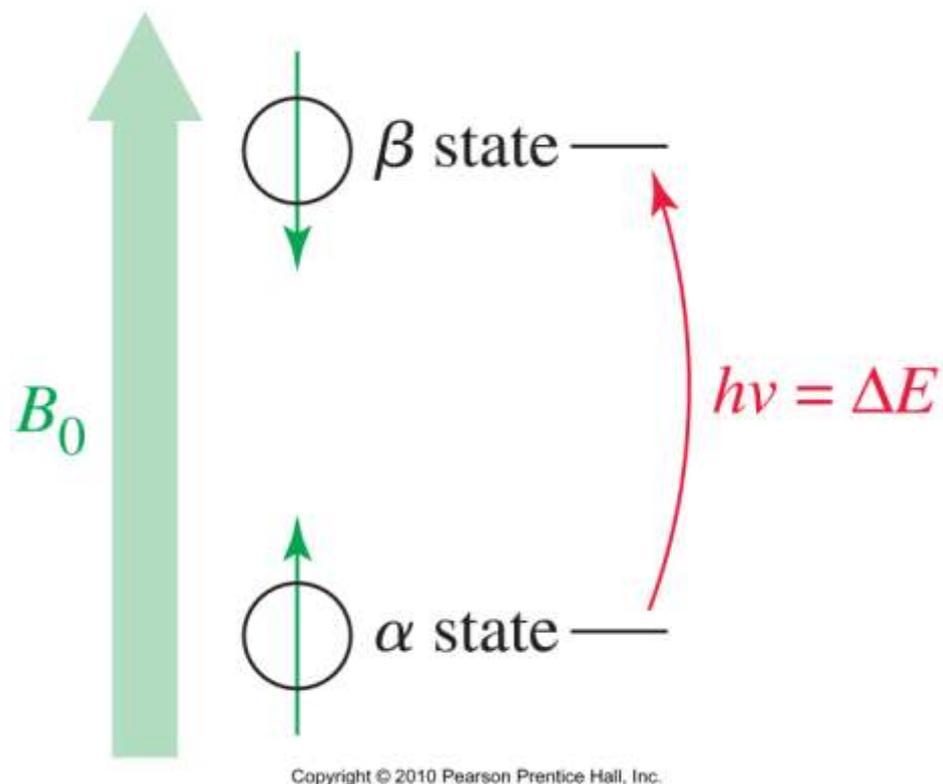
Proton Magnetic Moments



Copyright © 2010 Pearson Prentice Hall, Inc.

Two Energy States

- A nucleus is in resonance when it is irradiated with radio-frequency photons having energy equal to the energy difference between the spin states.
- Under these conditions, a proton in the alpha-spin state can absorb a photon and flip to the beta-spin state.



ΔE and Magnet Strength

- Energy difference is directly proportional to the magnetic field strength.

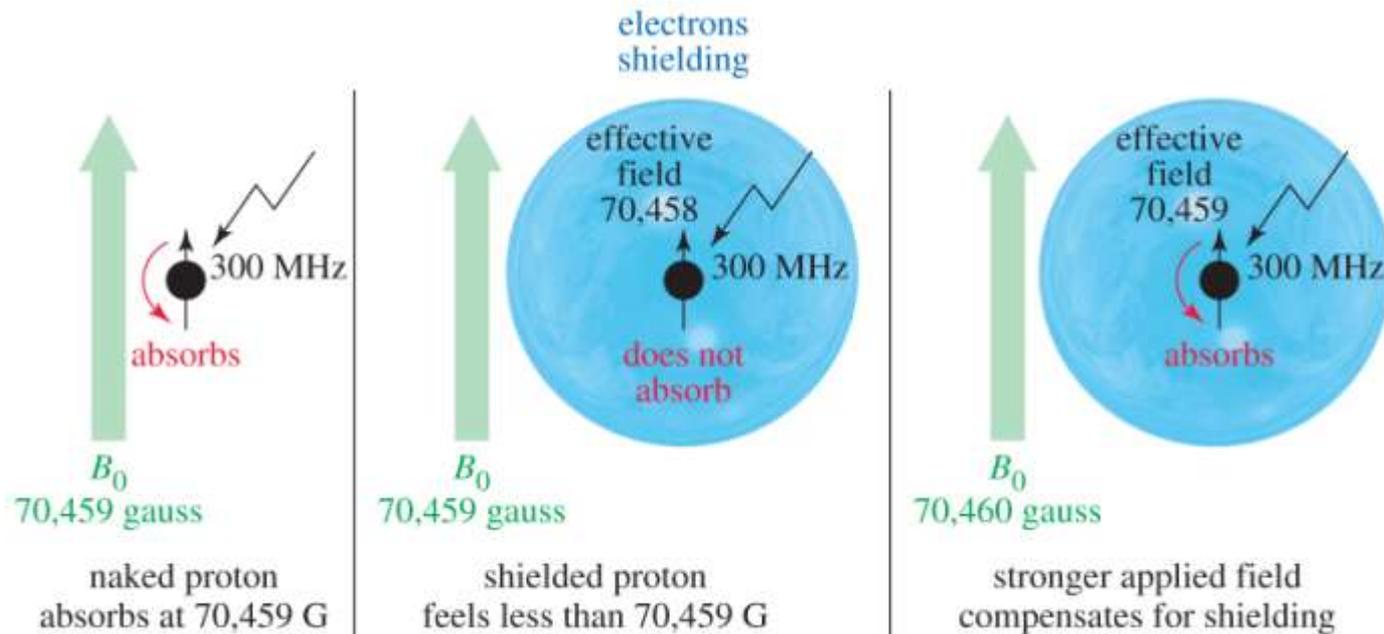
$$\Delta E = h\nu = \gamma \frac{h}{2\pi} B_0$$

- Gyromagnetic ratio, γ , is a constant for each nucleus ($26,753 \text{ s}^{-1}\text{gauss}^{-1}$ for H).
- In a 14,092 gauss field, a 60 MHz photon is required to flip a proton.
- Low energy, radio frequency.

Magnetic Shielding

- If all protons absorbed the same amount of energy in a given magnetic field, not much information could be obtained.
- But protons are surrounded by electrons that shield them from the external field.
- Circulating electrons create an induced magnetic field that opposes the external magnetic field.

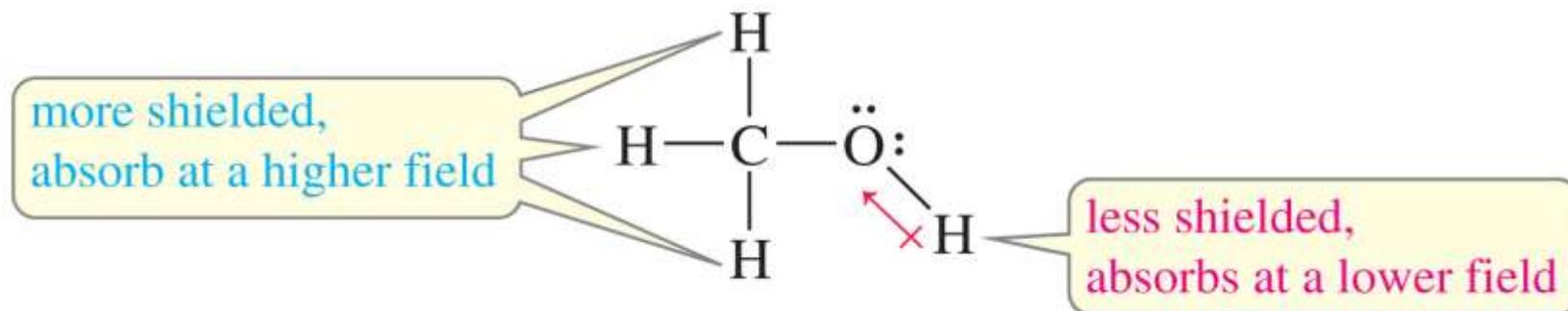
Shielded Protons



Copyright © 2010 Pearson Prentice Hall, Inc.

- A naked proton will absorb at 70,459 gauss.
- A shielded proton will not absorb at 70, 459 gauss so the magnetic field must be increased slightly to achieve resonance.

Protons in a Molecule



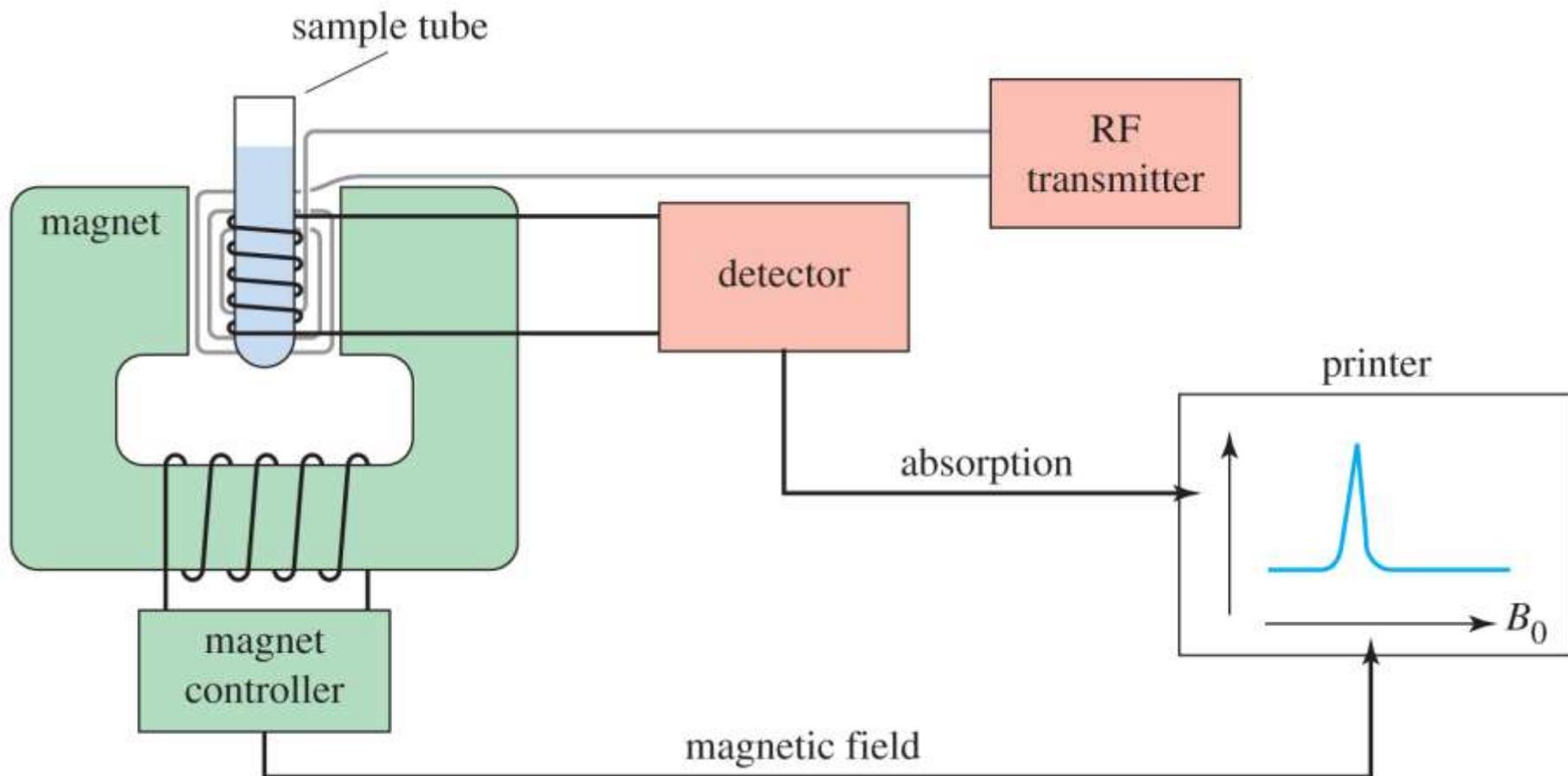
Copyright © 2010 Pearson Prentice Hall, Inc.

- Protons in different chemical environments are shielded by different amounts.
- The hydroxyl proton is not shielded as much as the methyl protons so the hydroxyl proton absorbs at a lower field than the methyl protons.
- We say that the proton is deshielded somewhat by the presence of the electronegative oxygen atom.

NMR Signals

- The ***number*** of signals shows how many different kinds of protons are present.
- The ***location*** of the signals shows how shielded or deshielded the proton is.
- The ***intensity*** of the signal shows the number of protons of that type.
- Signal ***splitting*** shows the number of protons on adjacent atoms.

The NMR Spectrometer



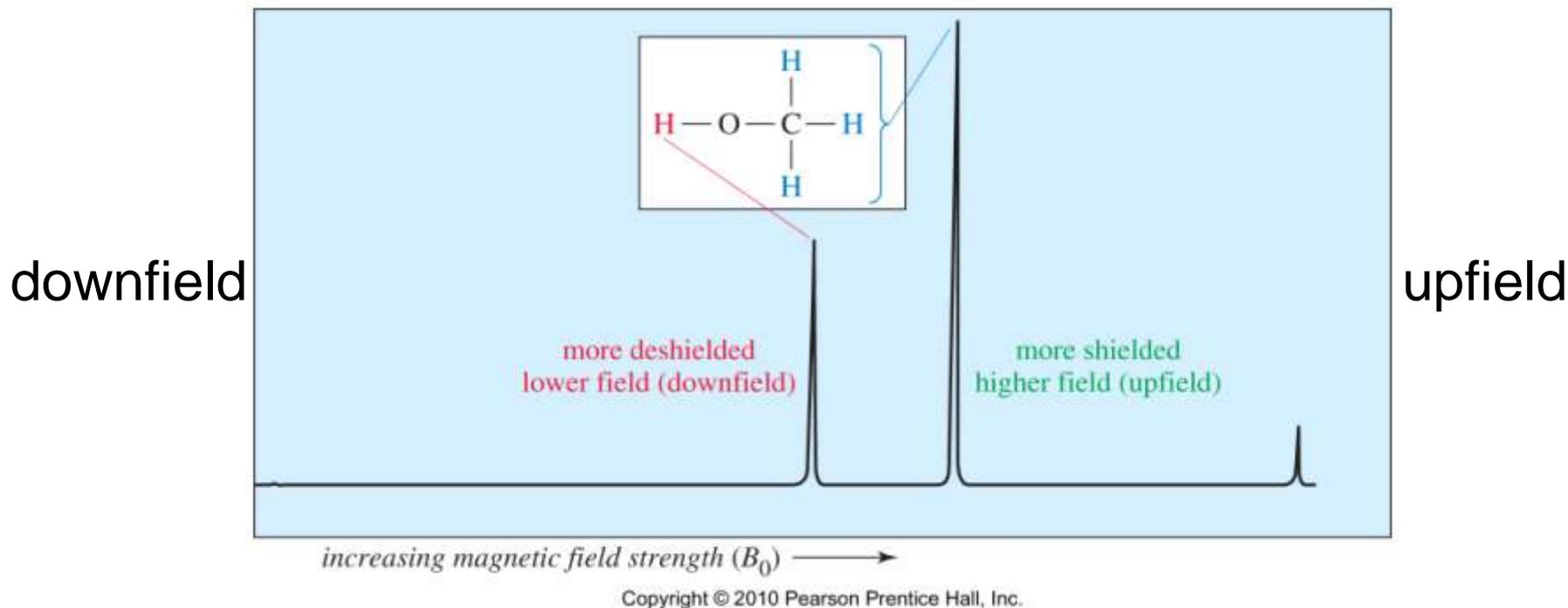
Copyright © 2010 Pearson Prentice Hall, Inc.

NMR Instrument

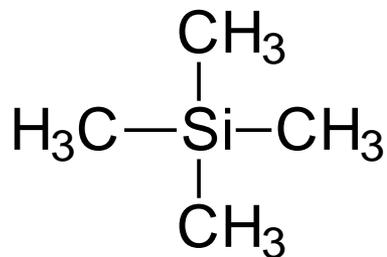


Copyright © 2010 Pearson Prentice Hall, Inc.

The NMR Graph



- The more shielded methyl protons appear toward the right of the spectrum (higher field); the less shielded hydroxyl proton appears toward the left (lower field).



Tetramethylsilane

- TMS is added to the sample as an internal standard.
- Since silicon is less electronegative than carbon, TMS protons are highly shielded.
- The TMS signal is defined as zero.
- Organic protons absorb downfield (to the left) of the TMS signal.

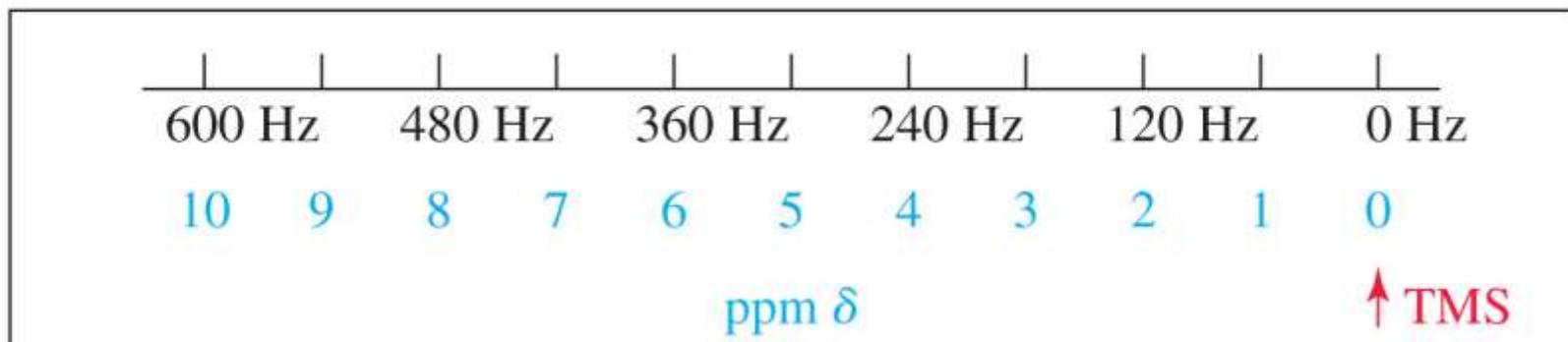
Chemical Shift

- Measured in parts per million.
- Ratio of shift downfield from TMS (Hz) to total spectrometer frequency (Hz).
- The chemical shift has the same value regardless of the machines (same value for 60, 100, or 300 MHz machine).
- Called the delta scale.

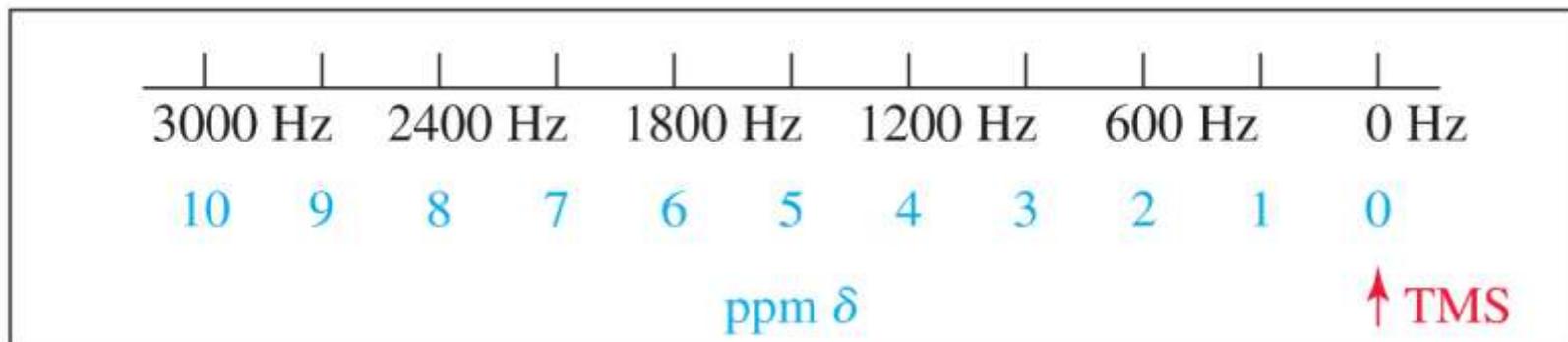
Delta Scale

$$\text{chemical shift, ppm } \delta = \frac{\text{shift downfield from TMS (in Hz)}}{\text{spectrometer frequency (in MHz)}}$$

60 MHz



300 MHz



Copyright © 2010 Pearson Prentice Hall, Inc.

Solved Problem 1

A 300-MHz spectrometer records a proton signal shifted 7.10 ppm from the TMS reference peak. Calculate the chemical shift in Hz.

(A) The chemical shift is the fraction of the spectrometer frequency, and expressed in ppm. Calculate the chemical shift in Hz.

(B) The chemical shift is unchanged at 60 MHz. Calculate the field shift in Hz.

Solution (a) The chemical shift is the fraction of the spectrometer frequency, and expressed in ppm. Calculate the chemical shift in Hz.

$$\frac{\text{shift downfield (Hz)}}{\text{spectrometer frequency (MHz)}} = \frac{2130 \text{ Hz}}{300 \text{ MHz}} = 7.10 \text{ ppm}$$

The chemical shift of this proton is $\delta 7.10$. The field shift is

$$70,459 \text{ gauss} \times (7.10 \times 10^{-6}) = 0.500 \text{ gauss}$$

(b) The chemical shift is unchanged at 60 MHz: $\delta 7.10$. The field shift is

$$14,092 \text{ gauss} \times (7.10 \times 10^{-6}) = 0.100 \text{ gauss}$$

The frequency shift is

$$60 \text{ MHz} \times (7.10 \times 10^{-6}) = 426 \text{ Hz}$$

Location of Signals

TABLE 13-2

Chemical Shifts of the Chloromethanes

Compound	Chemical Shift	Difference
$\begin{array}{c} \text{H} \\ \\ \text{H}-\text{C}-\text{H} \end{array}$	δ 0.2	
$\begin{array}{c} \text{H} \\ \\ \text{H}-\text{C}-\text{H} \\ \\ \text{H} \end{array}$	δ 3.0	2.8 ppm
$\begin{array}{c} \text{H} \\ \\ \text{H}-\text{C}-\text{Cl} \\ \\ \text{H} \\ \\ \text{Cl} \end{array}$	δ 5.3	2.3 ppm
$\begin{array}{c} \text{H} \\ \\ \text{H}-\text{C}-\text{Cl} \\ \\ \text{H} \\ \\ \text{Cl} \\ \\ \text{Cl} \end{array}$	δ 7.2	1.9 ppm

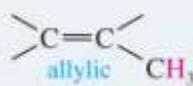
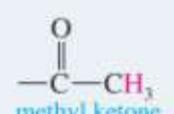
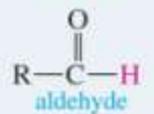
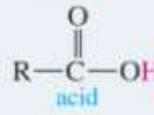
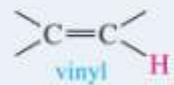
Note: Each chlorine atom added changes the chemical shift of the remaining methyl protons by 2 to 3 ppm. These changes are nearly additive.

- More electronegative atoms deshield more and give larger shift values.
- Effect decreases with distance.
- Additional electronegative atoms cause increase in chemical shift.

Typical Values

TABLE 13-3

Typical Values of Chemical Shifts

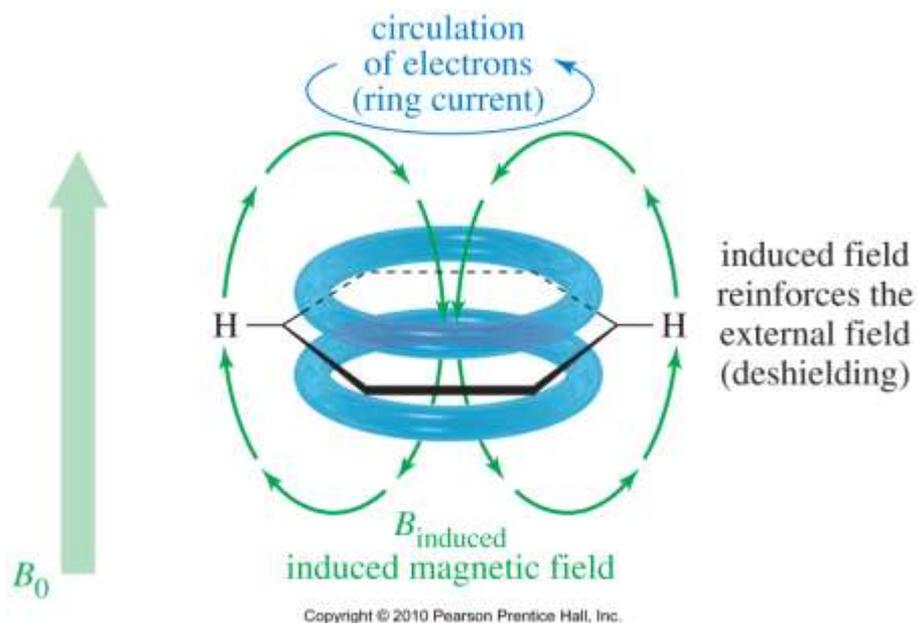
Type of Proton	Approximate δ	Type of Proton	Approximate δ
alkane ($-\text{CH}_3$) methyl	0.9	 allylic	1.7
alkane ($-\text{CH}_2-$) methylene	1.3	Ph—H aromatic	7.2
alkane ($-\text{CH}-$) methine	1.4	Ph—CH ₃ benzylic	2.3
 methyl ketone	2.1	 aldehyde	9–10
$-\text{C}\equiv\text{C}-\text{H}$ acetylenic	2.5	 acid	10–12
R—CH ₂ —X (X = halogen, O)	3–4	R—OH alcohol	variable, about 2–5
 vinyl	5–6	Ar—OH phenol	variable, about 4–7
		R—NH ₂ amine	variable, about 1.5–4

Note: These values are approximate, as all chemical shifts are affected by neighboring substituents. The numbers given here assume that alkyl groups are the only other substituents present. A more complete table of chemical shifts appears in Appendix 1.

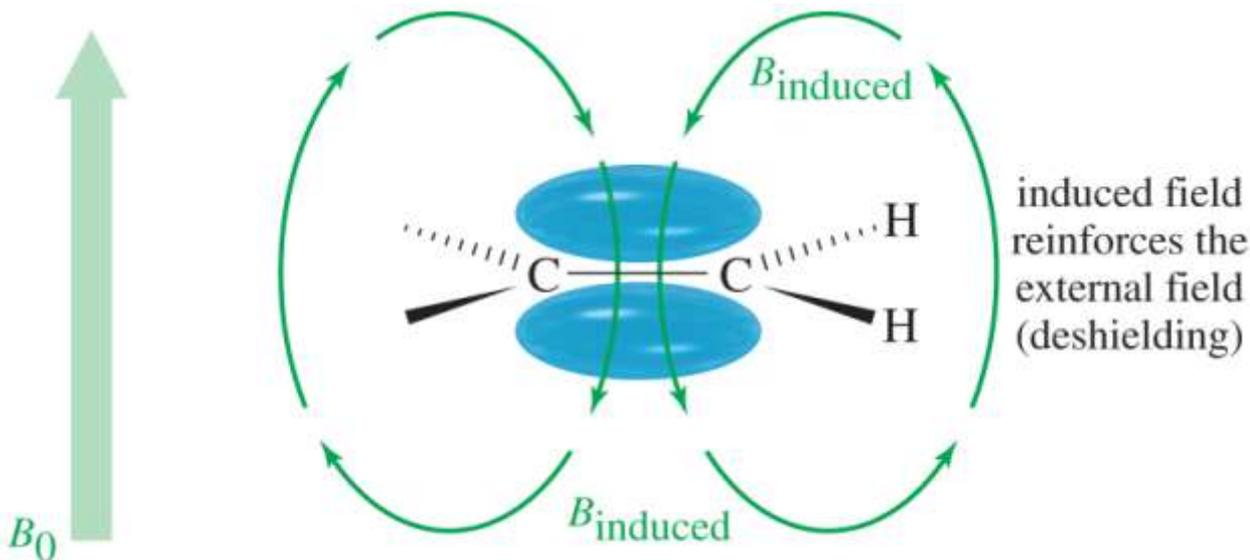
Copyright © 2010 Pearson Prentice Hall, Inc.

Magnetic Fields in Aromatic Rings

- The induced magnetic field of the circulating aromatic electrons opposes the applied magnetic field along the axis of the ring.
- Protons in the region where the induced field reinforces the applied field are deshielded and will appear at lower fields in the spectrum between $\delta 7-8$.



Magnetic Field of Alkenes

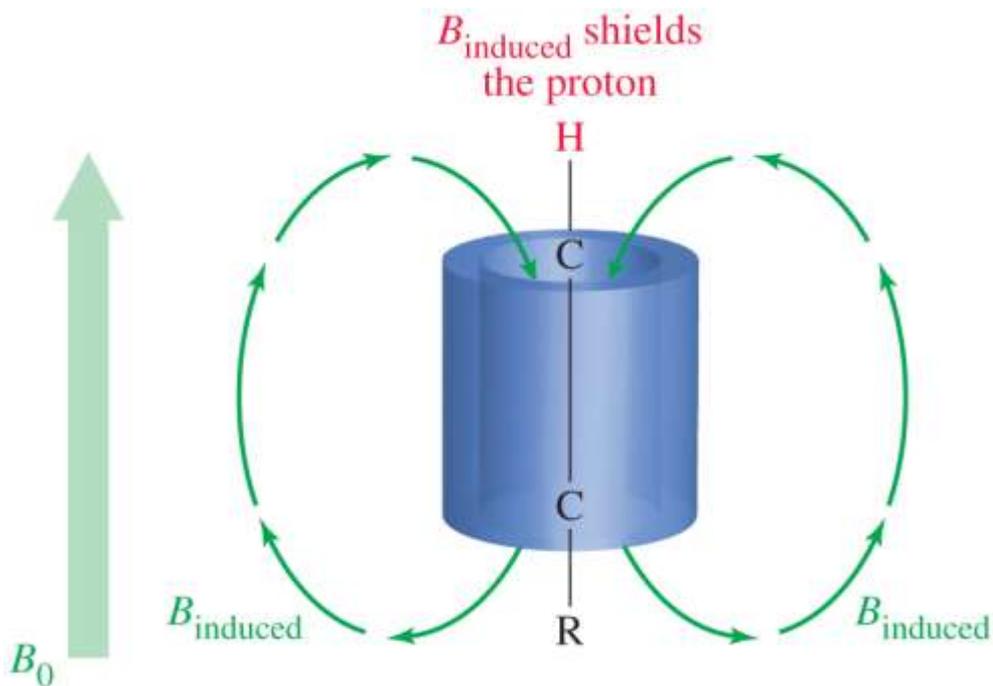


Copyright © 2010 Pearson Prentice Hall, Inc.

- The pi electrons of the double bond generate a magnetic field that opposes the applied magnetic field in the middle of the molecule but reinforces the applied field on the outside where the vinylic protons are located.
- This reinforcement will deshield the vinylic protons making them shift downfield in the spectrum to the range of $\delta 5-6$.

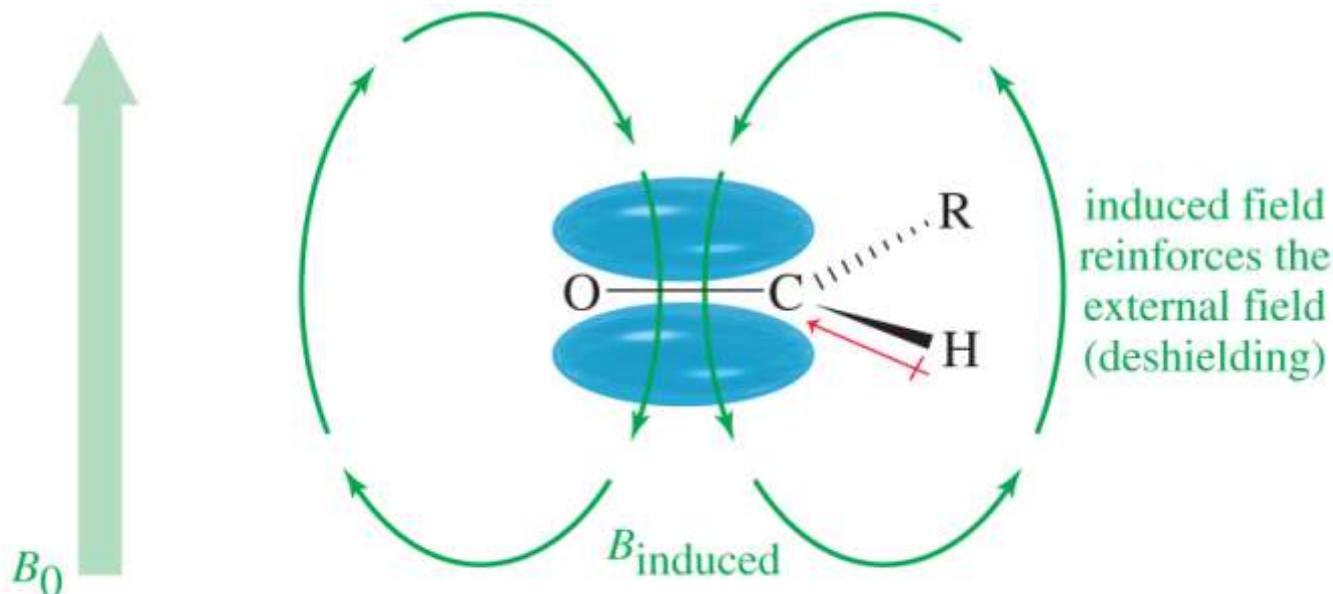
Magnetic Fields of Alkynes

- When the terminal triple bond is aligned with the magnetic field, the cylinder of electrons circulates to create an induced magnetic field.
- The acetylenic proton lies along the axis of this field, which opposes the external field.
- The acetylenic protons are shielded and will be found at $\delta 2.5$ (higher than vinylic protons).



Copyright © 2010 Pearson Prentice Hall, Inc.

Deshielding of the Aldehyde Proton



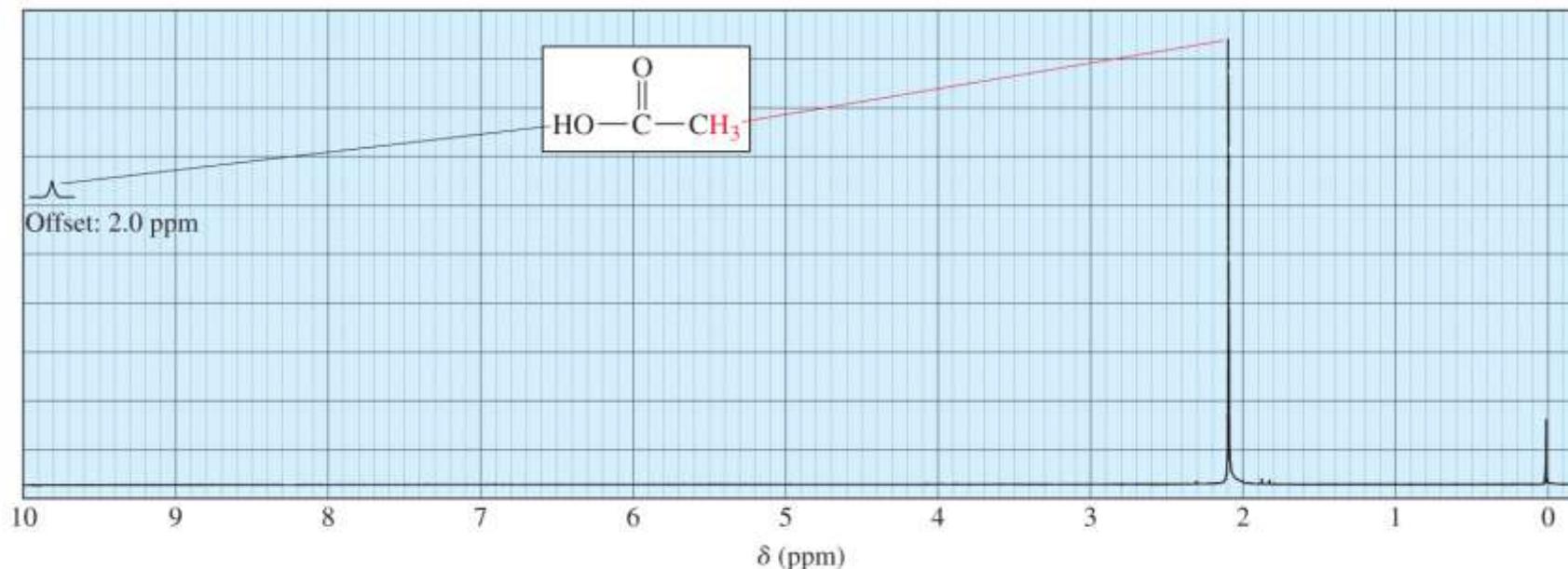
Copyright © 2010 Pearson Prentice Hall, Inc.

- Like a vinyl proton, the aldehyde proton is deshielded by the circulation of electrons in the pi bond.
- It is also deshielded by the electron-withdrawing effect of the carbonyl (C=O) group, giving a resonance between $\delta 9-10$.

O—H and N—H Signals

- The chemical shift of the acidic protons depends on concentration.
- Hydrogen bonding in concentrated solutions deshield the protons, so signal is around $\delta 3.5$ for N—H and $\delta 4.5$ for O—H.
- Proton exchanges between the molecules broaden the peak.

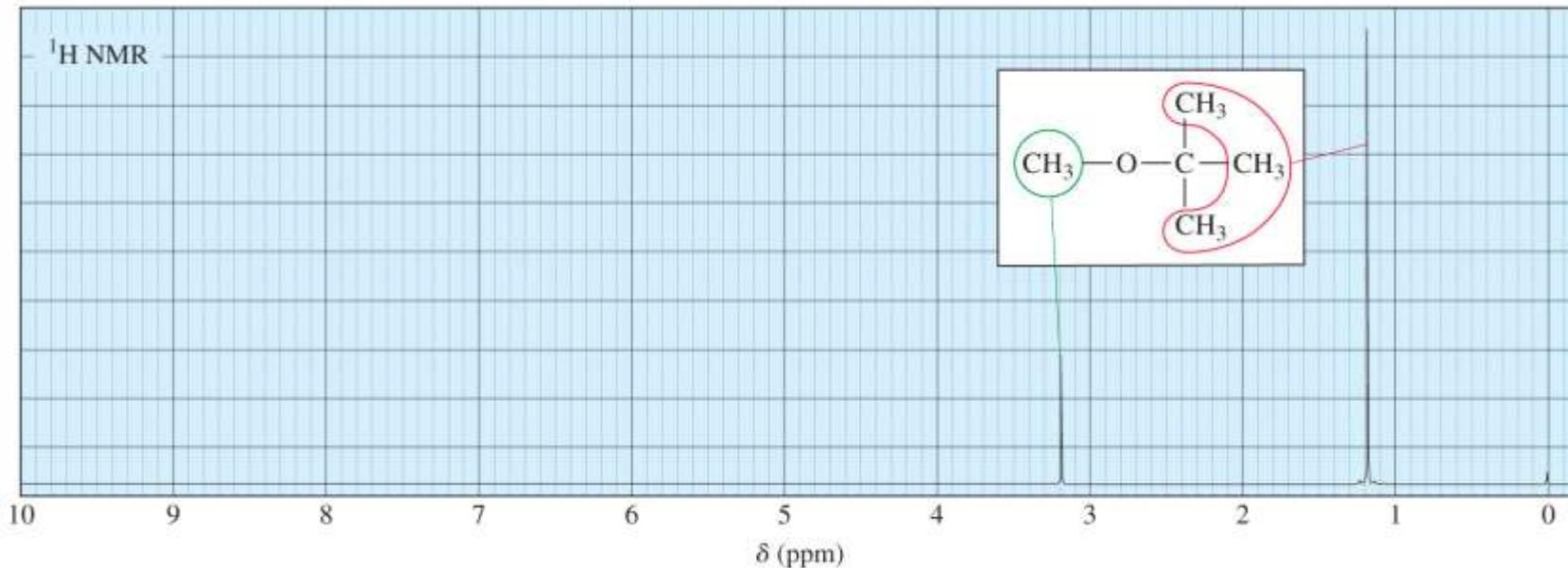
Carboxylic Acid Proton



Copyright © 2010 Pearson Prentice Hall, Inc.

- Because of the high polarity of the carboxylic acid O—H bond, the signal for the acidic proton will be at shifts greater than $\delta 10$.

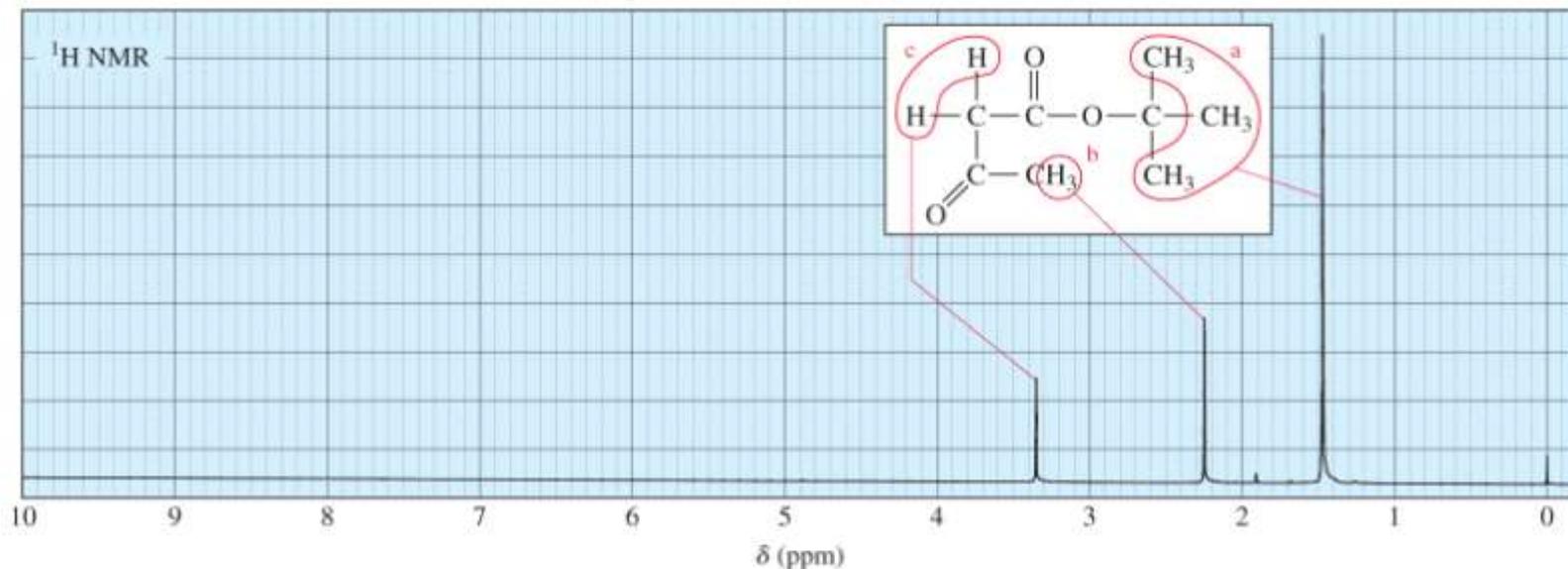
Number of Signals



Copyright © 2010 Pearson Prentice Hall, Inc.

- Methyl *tert*-butyl ether has two types of protons, giving two NMR signals.
- Chemically equivalent hydrogens have the same chemical shift. All the methyl groups of the *tert*-butyl group are equivalent and they produce only one signal.

tert-Butyl Acetoacetate

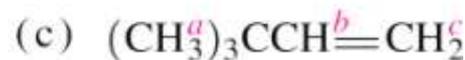
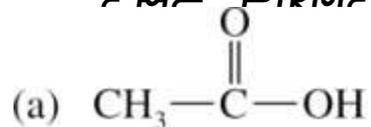


Copyright © 2010 Pearson Prentice Hall, Inc.

- The spectrum of *tert*-butyl acetoacetate has only three signals. The most shielded protons are the methyl groups of the *tert*-butyl. The most deshielded signal is the methylene (CH_2) because it is in between two carbonyl groups.

Solved Problem 2

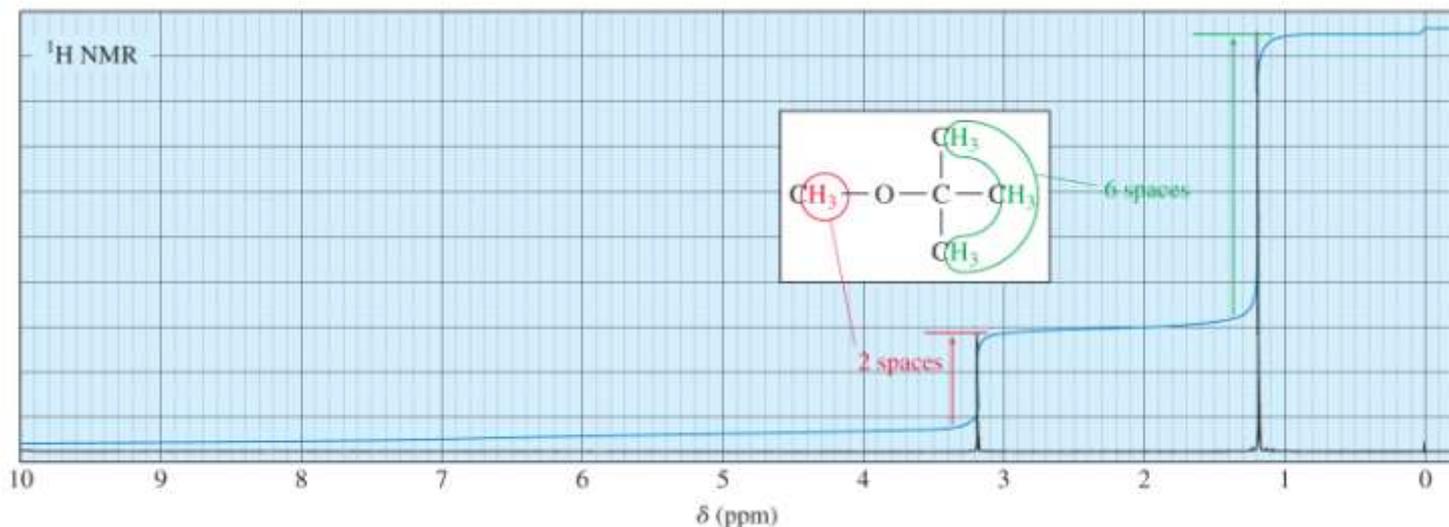
ඔබගේ පිටුවේ 13.3, ප්‍රදේශන ඒකක ඒකකයන්ගේ ඒකකයන්ගේ මට්ටම
 ඒකක ප්‍රදේශන මට්ටම ඒකක ප්‍රදේශන මට්ටම ප්‍රදේශන මට්ටම



Solution

- (a) The methyl group in acetic acid is next to a carbonyl group; Table 13-3 predicts a chemical shift of about $\delta 2.1$. (The experimental value is $\delta 2.10$). The acid proton ($-\text{COOH}$) should absorb between $\delta 10$ and $\delta 12$. (The experimental value is $\delta 11.4$, variable.)
- (b) Protons *a* are on the carbon atom bearing the chlorine, and they absorb between $\delta 3$ and $\delta 4$ (experimental: $\delta 3.7$). Protons *b* are one carbon removed, and they are predicted to absorb about $\delta 1.7$, like the β protons in 1-bromobutane (experimental: $\delta 1.8$). The methyl protons *c* will be nearly unaffected, absorbing around $\delta 0.9$ ppm (experimental: $\delta 1.0$).
- (c) Methyl protons *a* are expected to absorb around $\delta 0.9$ (experimental: $\delta 1.0$). The vinyl protons *b* and *c* are expected to absorb between $\delta 5$ and $\delta 6$ (experimental $\delta 5.8$ for *b* and $\delta 4.9$ for *c*).

Intensity of Signals: Integration



Copyright © 2010 Pearson Prentice Hall, Inc.

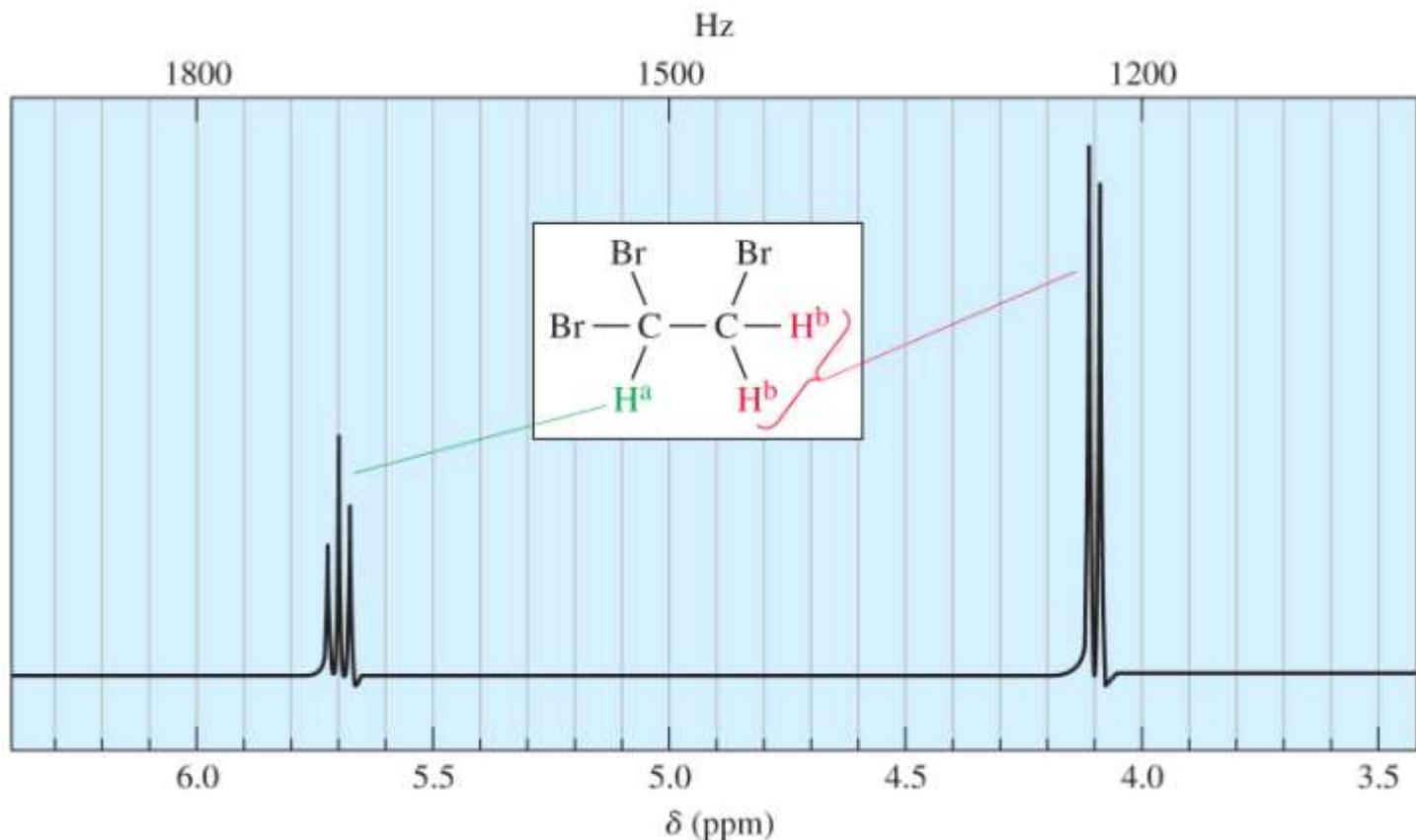
- The area under each peak is proportional to the number of hydrogens that contribute to that signal.
- The integration will have a trace for the *tert*-butyl hydrogens that is 3 times as large as the trace for the methyl hydrogens. The relative area for methyl and *tert*-butyl hydrogens is 1:3.

Spin-Spin Splitting

- Nonequivalent protons on adjacent carbons have magnetic fields that may align with or oppose the external field.
- This magnetic coupling causes the proton to absorb slightly downfield when the external field is reinforced and slightly upfield when the external field is opposed.
- All possibilities exist, so signal is split.

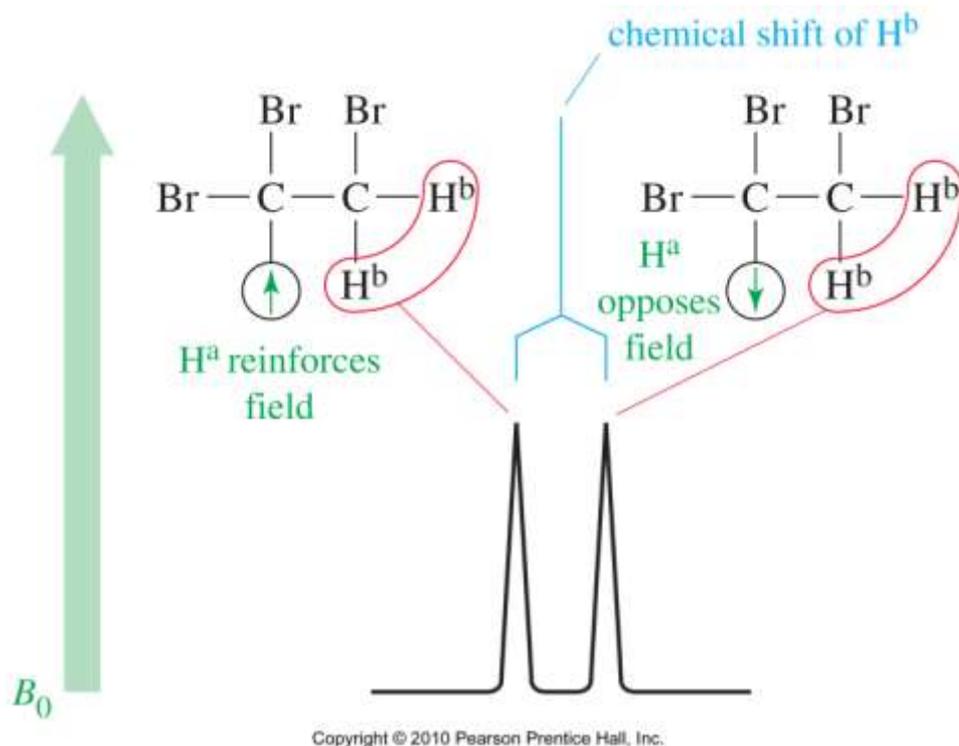
1,1,2-Tribromoethane

Nonequivalent protons on adjacent carbons.



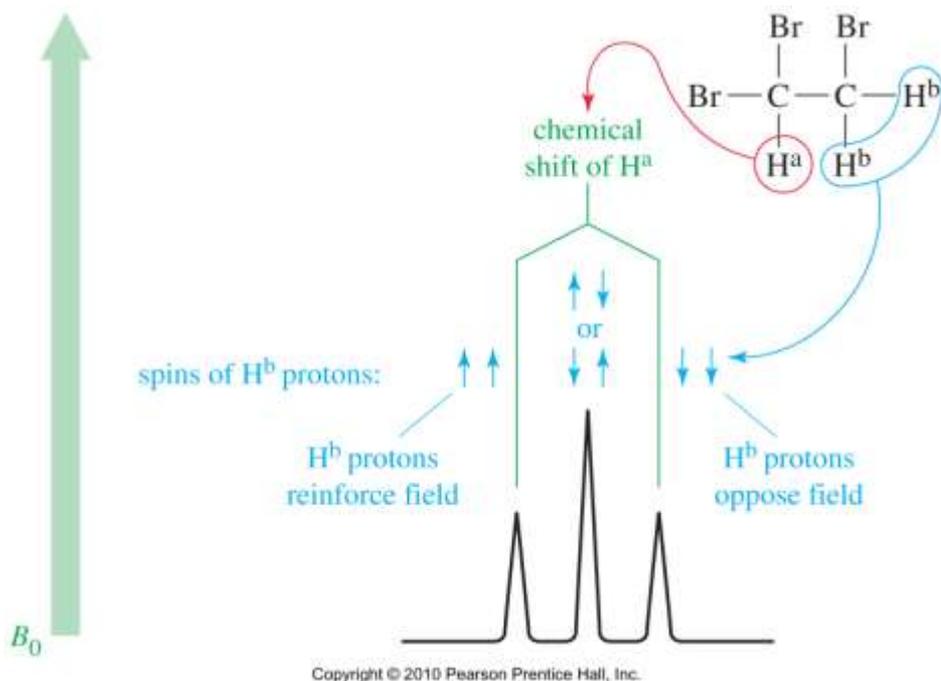
Copyright © 2010 Pearson Prentice Hall, Inc.

Doublet: One Adjacent Proton



- H^b can feel the alignment of the adjacent proton H^a .
- When H^a is aligned with the magnetic field, H^b will be deshielded.
- When H^a is aligned with the magnetic field, H^b will be shielded.
- The signal is split in two and it is called a doublet.

Triplet: Two Adjacent Protons



- When both H^b are aligned with the magnetic field, H^a will be deshielded.
- When both H^b are aligned with the magnetic field, H^a will be deshielded.
- It is more likely that one H^b will be aligned with the field and the other H^b against the field. The signal will be at its normal position.
- The signal is split in three and it is called a triplet.

The $N + 1$ Rule

If a signal is split by N equivalent protons, it is split into $N + 1$ peaks.

Relative Peak Intensities of Symmetric Multiplets

Number of Equivalent Protons Causing Splitting	Number of Peaks (multiplicity)	Area Ratios (Pascal's triangle)
0	1 (singlet)	1
1	2 (doublet)	1 1
2	3 (triplet)	1 2 1
3	4 (quartet)	1 3 3 1
4	5 (quintet)	1 4 6 4 1
5	6 (sextet)	1 5 10 10 5 1
6	7 (septet)	1 6 15 20 15 6 1

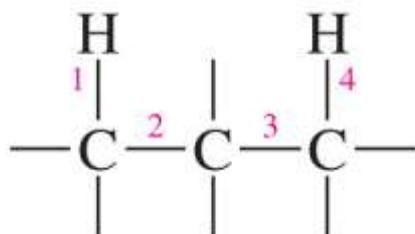
Copyright © 2010 Pearson Prentice Hall, Inc.

Spin-spin Splitting Distance

- Equivalent protons do not split each other.
- Protons bonded to the same carbon will split each other if they are nonequivalent.
- Protons on adjacent carbons normally will split each other.
- Protons separated by four or more bonds will not split each other.

Long-Range Coupling

Bonded to nonadjacent carbons: four or more bonds between protons

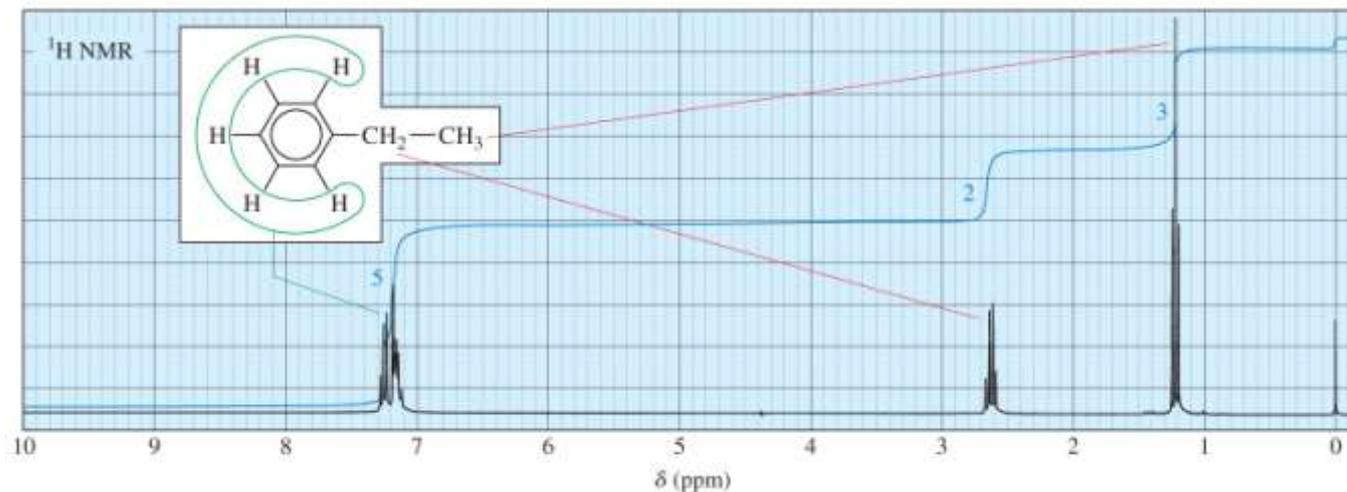


spin-spin splitting is *not* normally observed

Copyright © 2010 Pearson Prentice Hall, Inc.

- When the hydrogen atoms are four bonds or more apart, spin–spin splitting is not normally observed. When it actually does occur it is called “long-range coupling.”

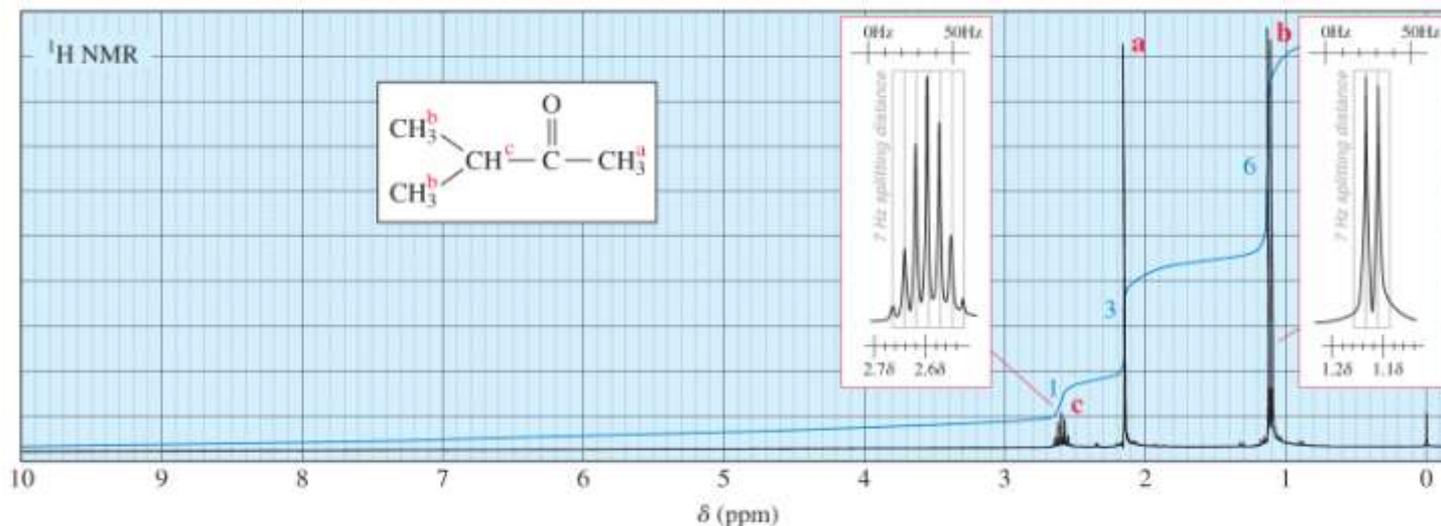
Splitting for Ethyl Groups



Copyright © 2010 Pearson Prentice Hall, Inc.

- The hydrogens on the CH_3 are affected by the two neighboring hydrogens on the adjacent CH_2 group. According to the $N+1$ rule, the CH_3 signal will be split into $(2+1) = 3$. This is a *triplet*.
- The hydrogens on the CH_2 group are affected by the three hydrogens on the adjacent CH_3 groups. The $N+1$ rule for the CH_2 signal will be split into $(3+1) = 4$. This is called a *quartet*.

Splitting for Isopropyl Groups

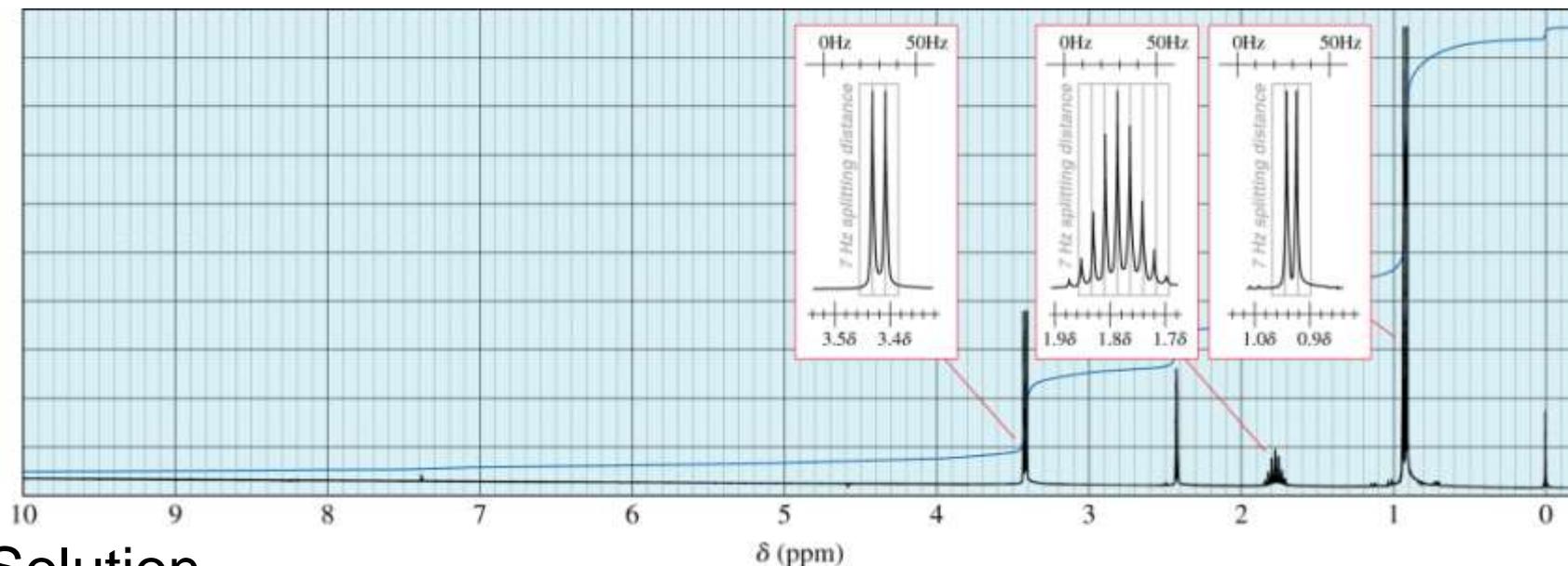


Copyright © 2010 Pearson Prentice Hall, Inc.

- The hydrogen on the CH has 6 adjacent hydrogens. According to the N+1 rule, the CH signal will be split into $(6+1) = 7$. This is called a *septet*.
- The two CH_3^b are equivalent so they give the same signal. They have one adjacent hydrogen (CH) so their signal will be: N+1, $1+1 = 2$ (*doublet*).

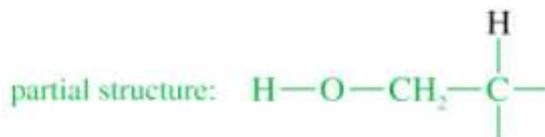
Solved Problem 3

PROPOSE A STRUCTURE FOR THE COMPOUNDS OF MOLECULAR FORMULA $C_4H_{10}O$ WHICH SHOW THE FOLLOWING SPECTRA.



Solution

The molecular formula $C_4H_{10}O$ indicates no elements of unsaturation. Four types of hydrogens appear in this spectrum, in the ratio 2:1:1:6. The singlet (one proton) at $\delta 2.4$ might be a hydroxyl group, and the signal (two protons) at $\delta 3.4$ corresponds to protons on a carbon atom bonded to oxygen. The $\delta 3.4$ signal is a doublet, implying that the adjacent carbon atom bears one hydrogen.

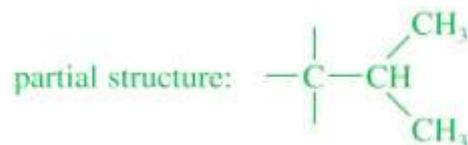


Solved Problem 3 (Continued)

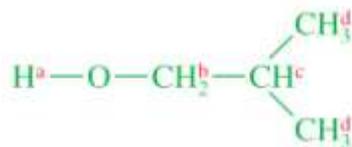
Solution (Continued)

(Since we cannot be certain that the $\delta 2.4$ absorption is actually a hydroxyl group, we might consider shaking the sample with D_2O . If the 2.4 ppm absorption represents a hydroxyl group, it will shrink or vanish after shaking with D_2O .)

The signals at $\delta 1.8$ and $\delta 0.9$ resemble the pattern for an isopropyl group. The integral ratio of 1:6 supports this assumption. Since the methine (—CH—) proton of the isopropyl group absorbs at a fairly high field, the isopropyl group must be bonded to a carbon atom rather than an oxygen.



Our two partial structures add to a total of six carbon atoms (compared with the four in the molecular formula) because two of the carbon atoms appear in both partial structures. Drawing the composite of the partial structures, we have isobutyl alcohol:

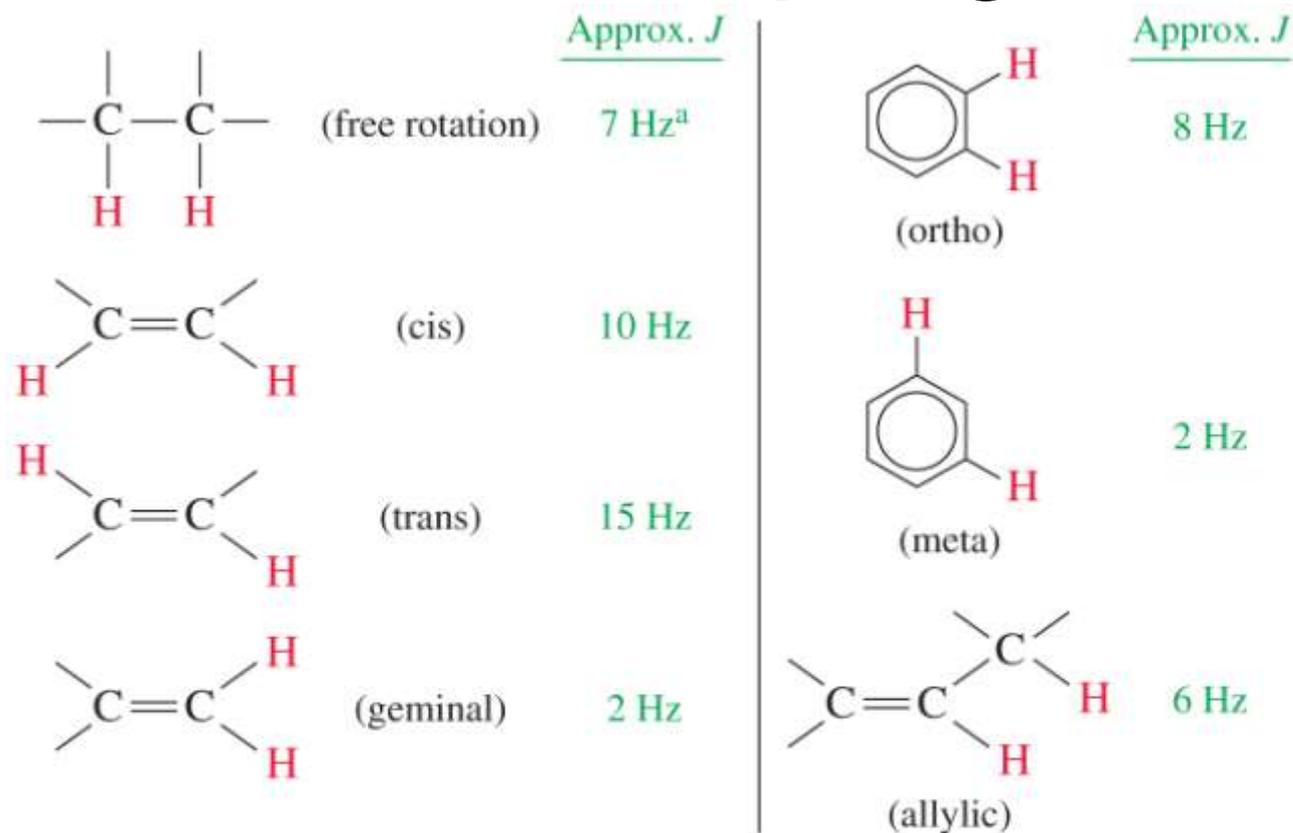


This structure must be rechecked to make sure that it has the correct molecular formula and that it accounts for all the structural evidence provided by the spectrum (Problem 13-23).

Coupling Constants

- The coupling constant is the distance between the peaks of a multiplet (in Hz).
- Coupling constants are independent of strength of the external field.
- Multiplets with the same coupling constants may come from adjacent groups of protons that split each other.

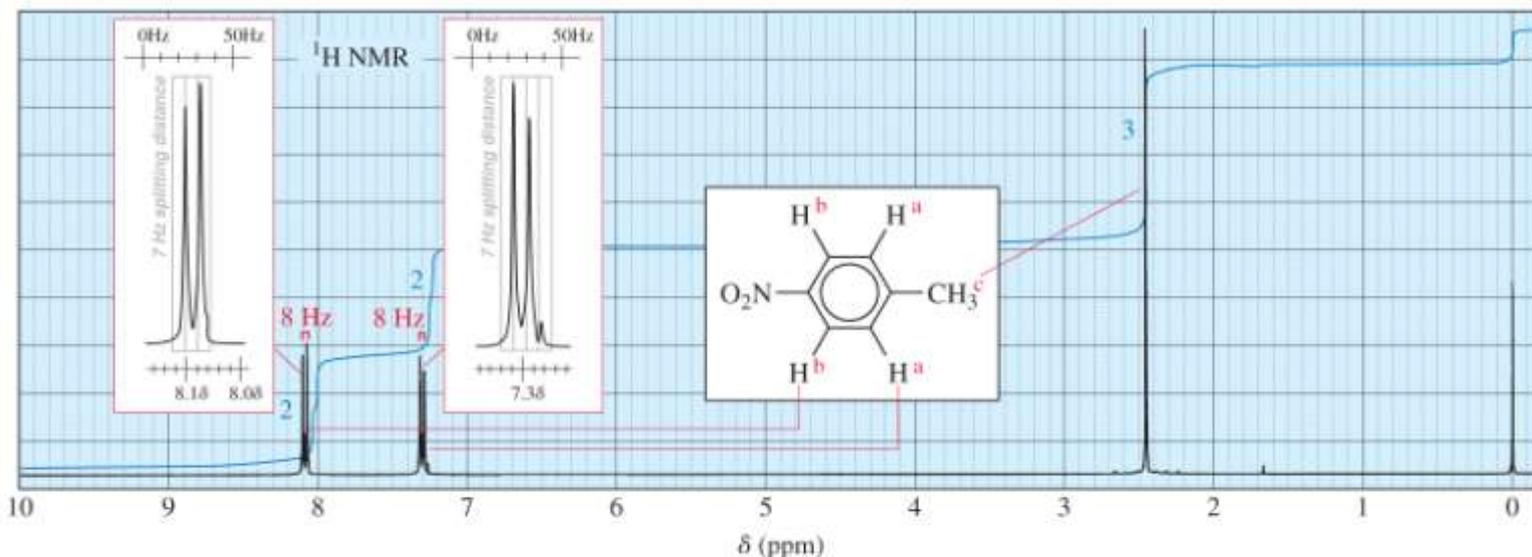
Values for Coupling Constants



^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.

Copyright © 2010 Pearson Prentice Hall, Inc.

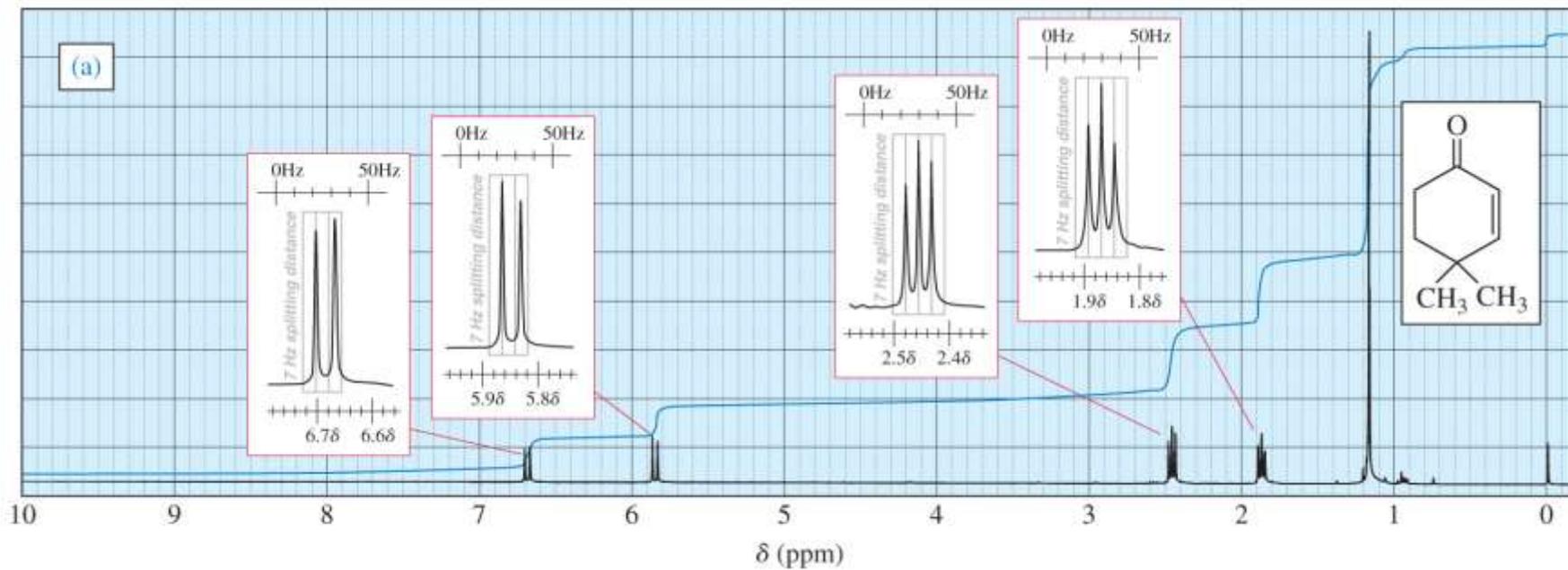
Proton NMR for *para*-Nitrotoluene



Copyright © 2010 Pearson Prentice Hall, Inc.

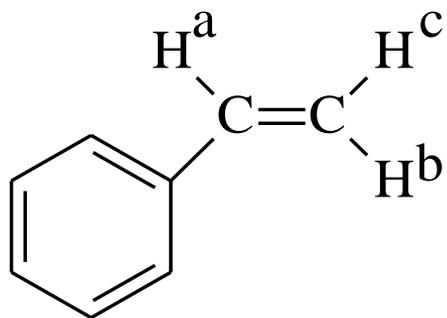
- *para*-Nitrotoluene has two pairs of equivalent aromatic protons a and b. Since the coupling constant for ortho hydrogens is approximately 8 Hz, the peaks of the signal will be separated by around 8 Hz.

Vinylic Coupling Constants



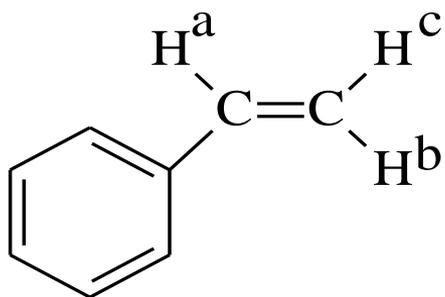
Copyright © 2010 Pearson Prentice Hall, Inc.

- There are 2 vinylic protons in 4,4-dimethylcyclohex-2-ene-1-one and they are *cis*. The coupling constant for *cis* coupling is approximately 10 Hz so the peaks should be separated by that amount.

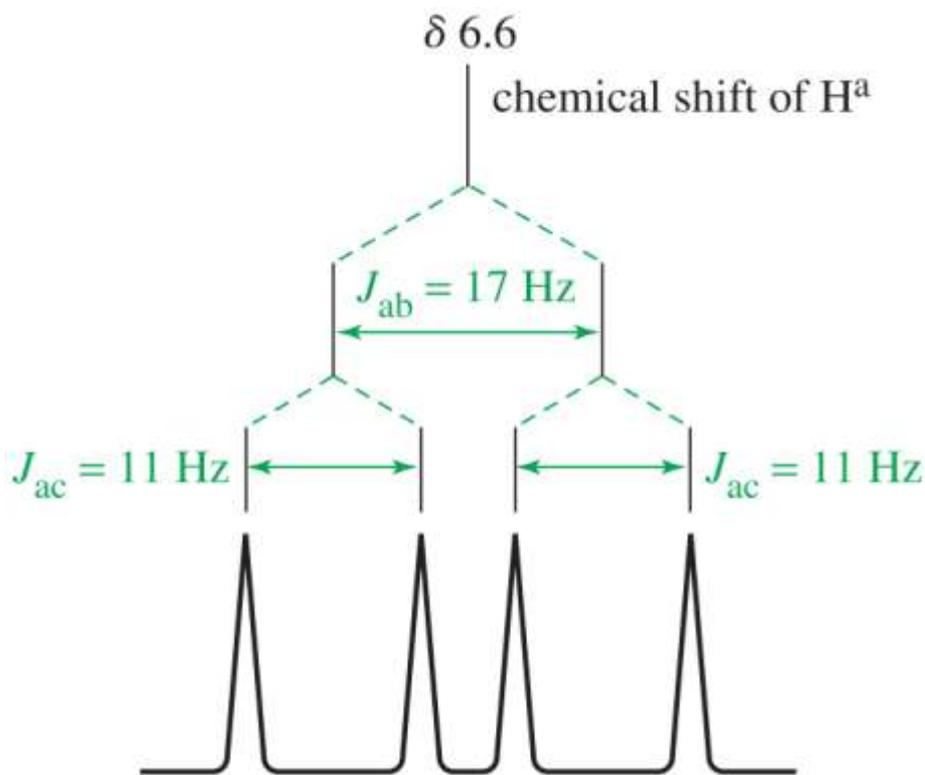


Complex Splitting

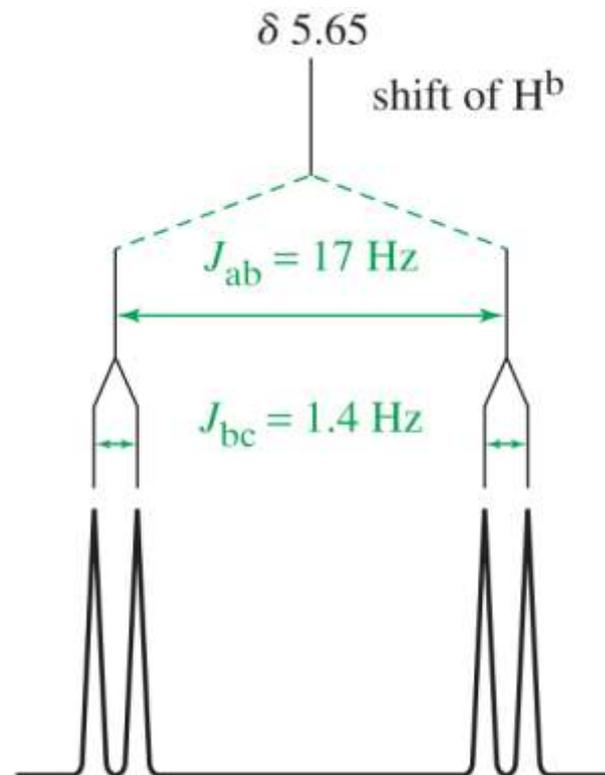
- Signals may be split by adjacent protons, different from each other, with different coupling constants.
- Example: H^a of styrene which is split by an adjacent H *trans* to it ($J = 17$ Hz) and an adjacent H *cis* to it ($J = 11$ Hz).



Splitting Tree

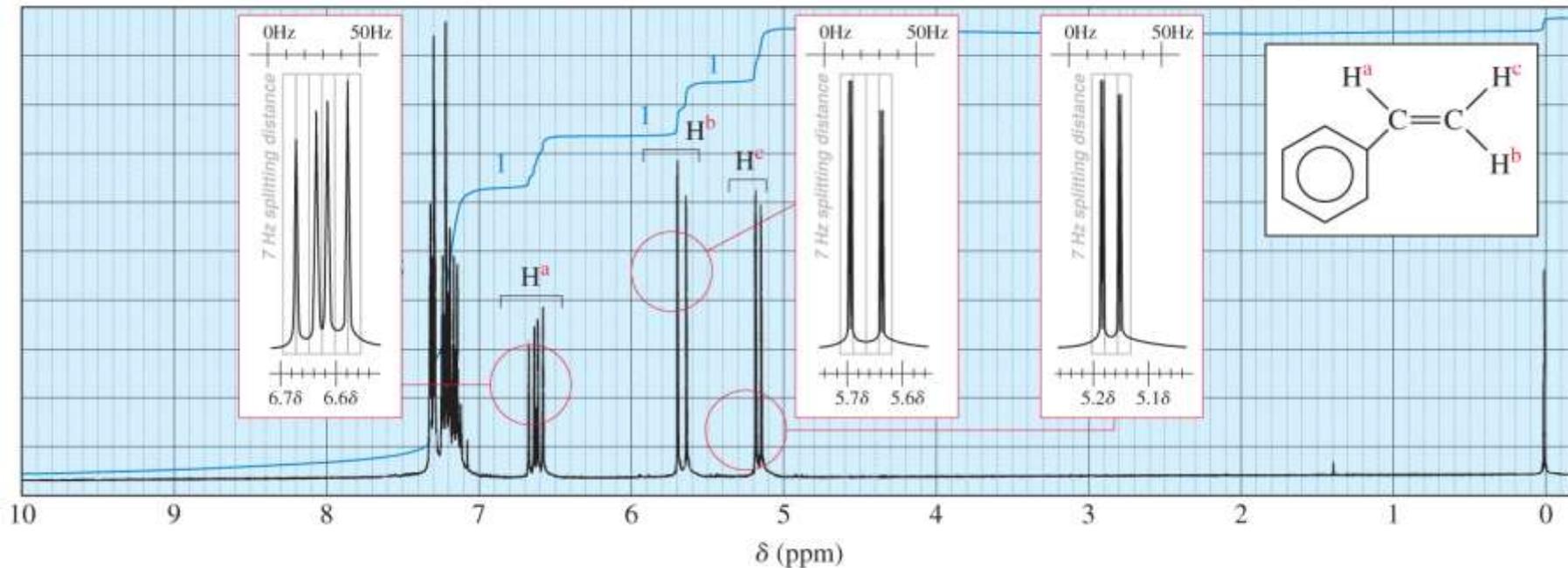


Copyright © 2010 Pearson Prentice Hall, Inc.



Copyright © 2010 Pearson Prentice Hall, Inc.

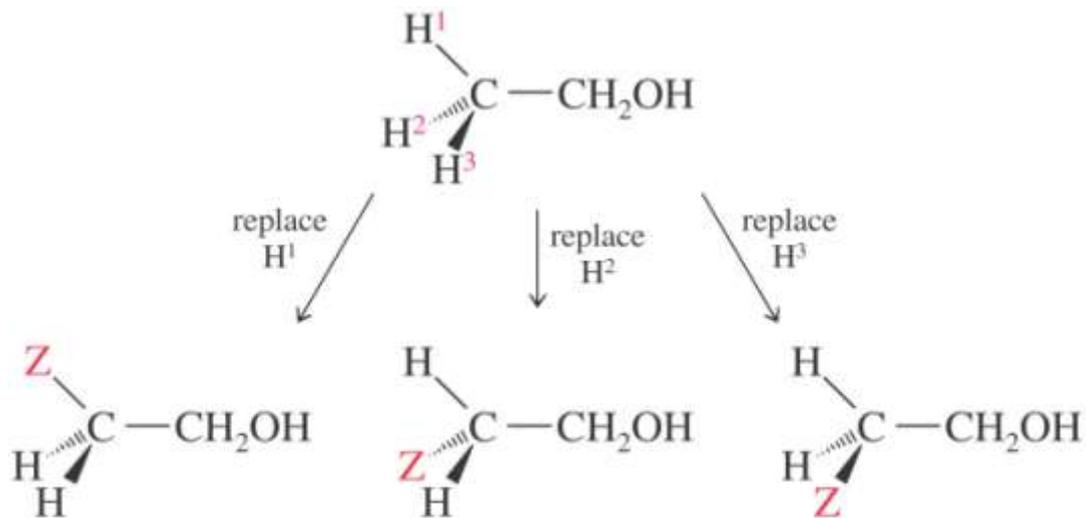
^1H -NMR Spectrum of Styrene



Copyright © 2010 Pearson Prentice Hall, Inc.

Stereochemical Nonequivalence

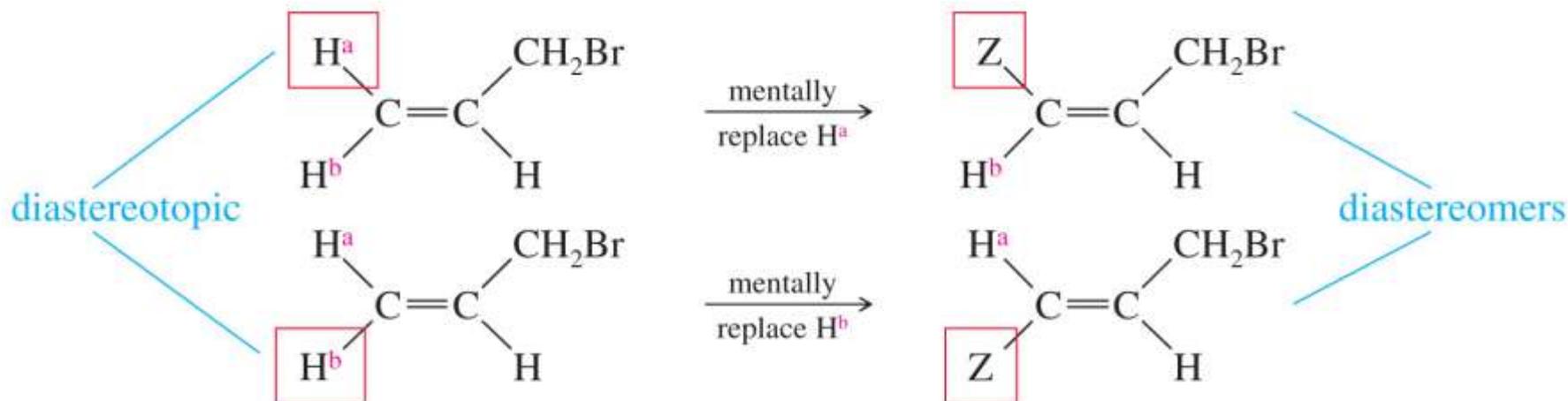
- If the replacement of each of the protons of a —CH_2 group with an imaginary “Z” gives stereoisomers, then the protons are non-equivalent and will split each other.



different conformations of the same compound

Copyright © 2006 Pearson Prentice Hall, Inc.

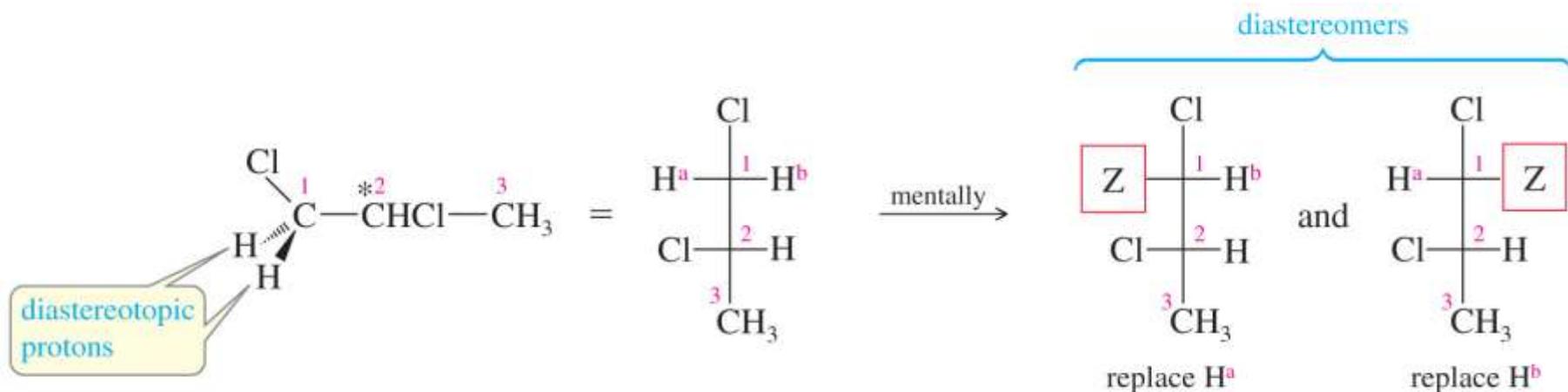
Diastereotopic Vinylic Protons



Copyright © 2010 Pearson Prentice Hall, Inc.

- Replacing the cis hydrogen gives the cis diastereomer, and replacing the trans hydrogen makes the trans diastereomer.
- Because the two imaginary products are diastereomers, these protons are called diastereotopic protons.
- Diastereotopic hydrogens are capable of splitting each other.

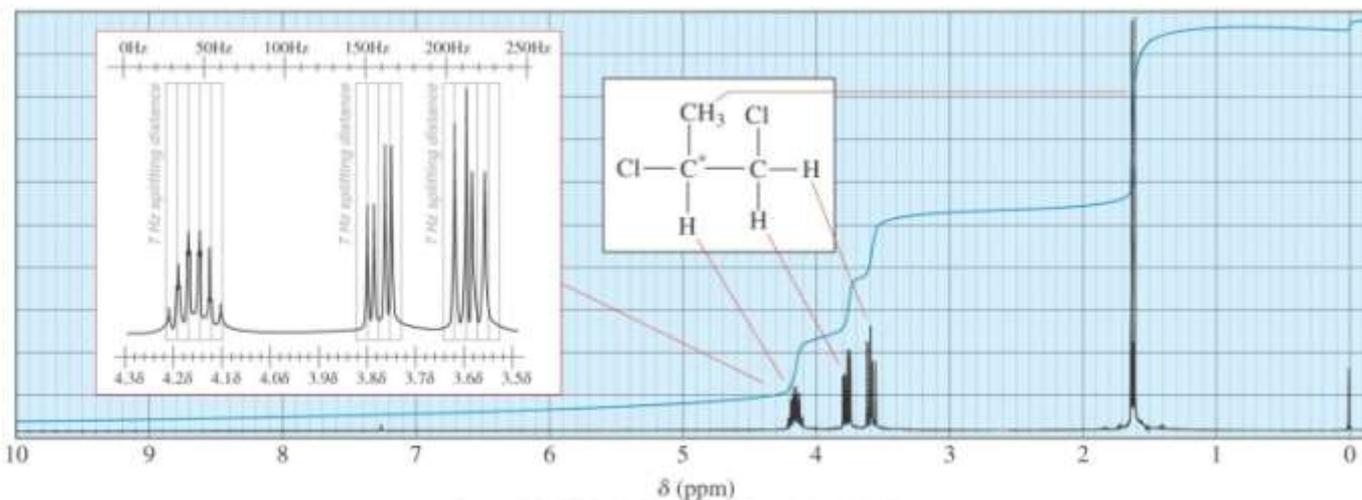
Diastereotopic Protons



Copyright © 2010 Pearson Prentice Hall, Inc.

- The two protons on the —CH₂Cl group are diastereotopic; their imaginary replacements give diastereomers.
- Diastereotopic protons are usually vicinal to stereocenters (chiral carbons).

Proton NMR Spectrum of 1,2-dichloropropane



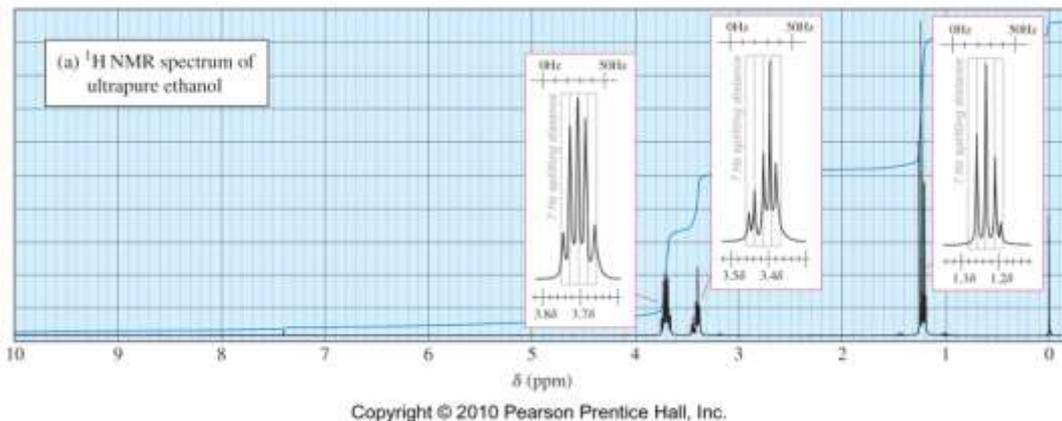
Copyright © 2006 Pearson Prentice Hall, Inc.

- Proton NMR spectrum of 1,2-dichloropropane shows distinct absorptions for the methylene protons on C1.
- These hydrogen atoms are diastereotopic and are chemically non-equivalent.

Time Dependence

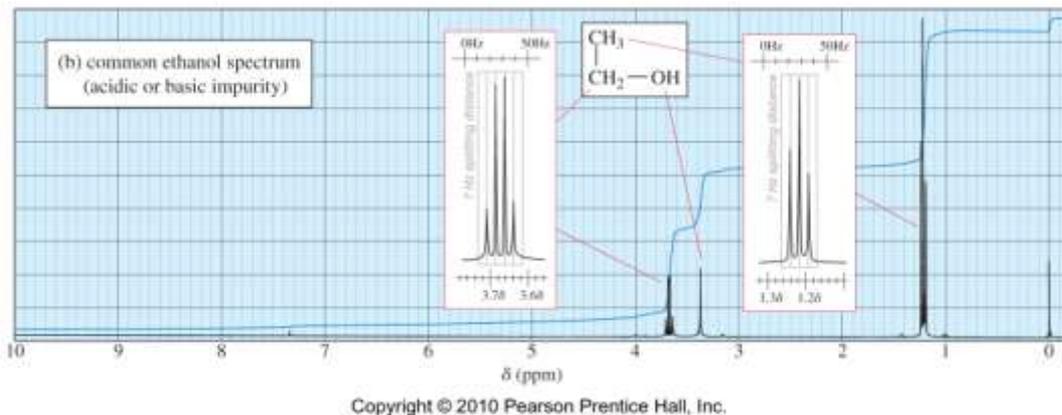
- Molecules are tumbling relative to the magnetic field, so NMR is an averaged spectrum of all the orientations.
- Axial and equatorial protons on cyclohexane interconvert so rapidly that they give a single signal.
- Proton transfers for OH and NH may occur so quickly that the proton is not split by adjacent protons in the molecule.

pure



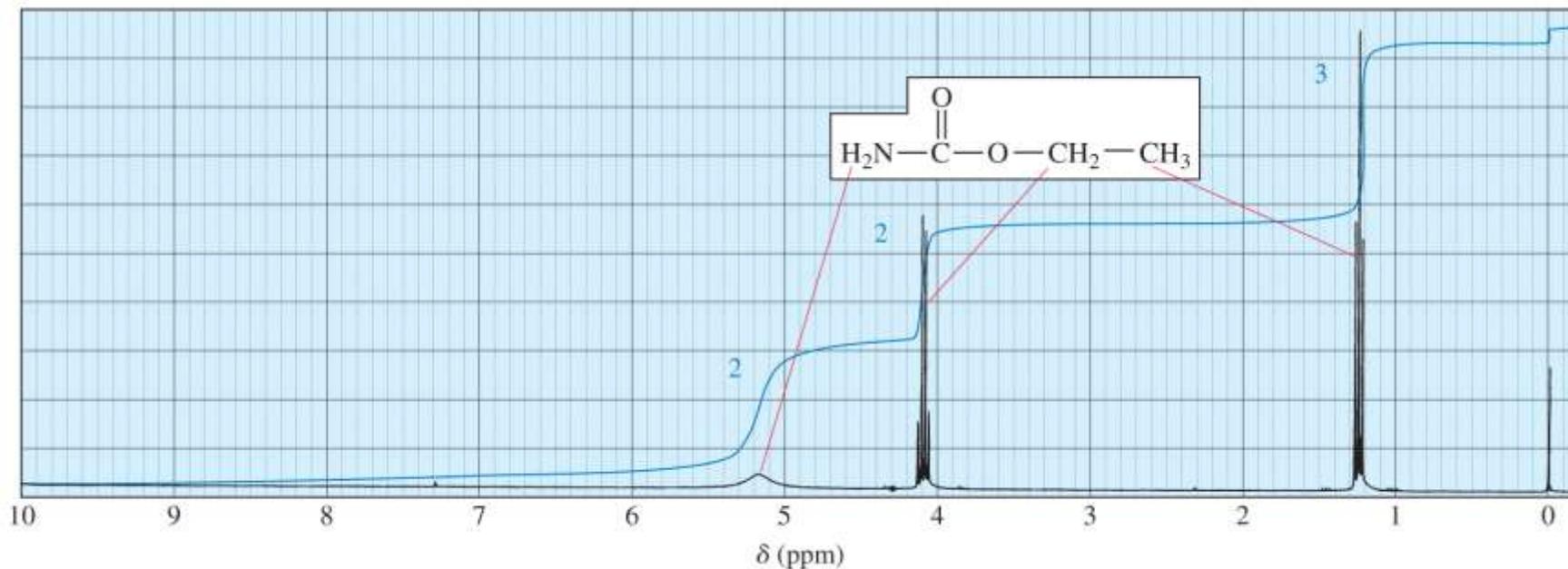
- # Hydroxyl Proton
- Ultrapure samples of ethanol show splitting.

impure



- Ethanol with a small amount of acidic or basic impurities will not show splitting.

N—H Proton

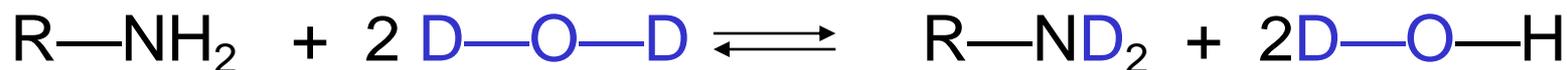
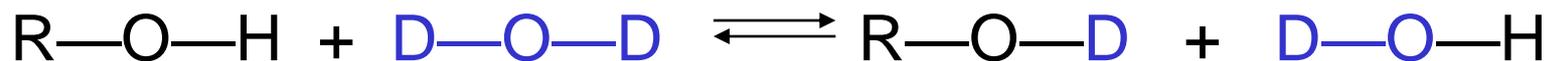


Copyright © 2010 Pearson Prentice Hall, Inc.

- The acidic proton on the nitrogen has a moderate rate of exchange.
- Peak may be broad.

Identifying the O—H or N—H Peak

- Chemical shift will depend on concentration and solvent.
- To verify that a particular peak is due to O—H or N—H, shake the sample with D₂O to exchange the H for a D. The deuterium is invisible in the proton NMR so the original signal for the OH will disappear.

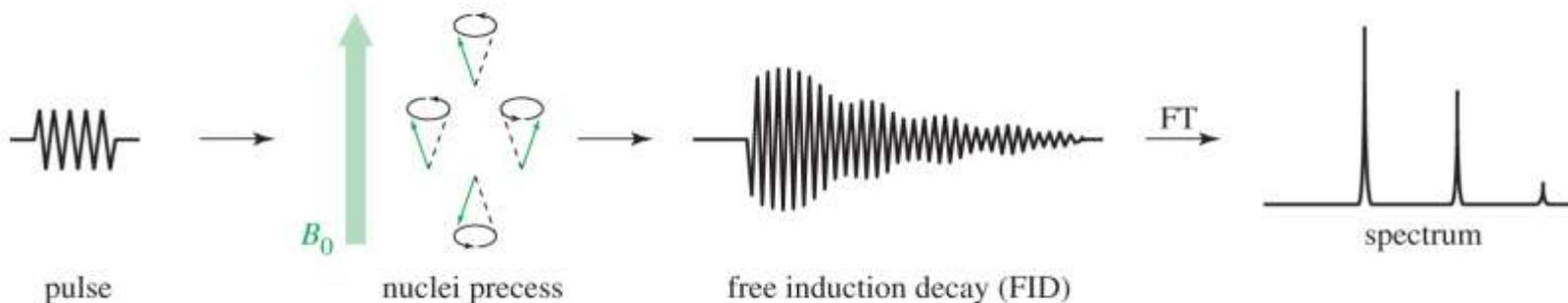


Carbon-13 NMR

- Carbon-12 (^{12}C) has no magnetic spin.
- Carbon-13 (^{13}C) has a magnetic spin, but is only 1% of the carbon in a sample.
- The gyromagnetic ratio of ^{13}C is one-fourth of that of ^1H .
- For carbon a technique called Fourier transform spectroscopy is used.

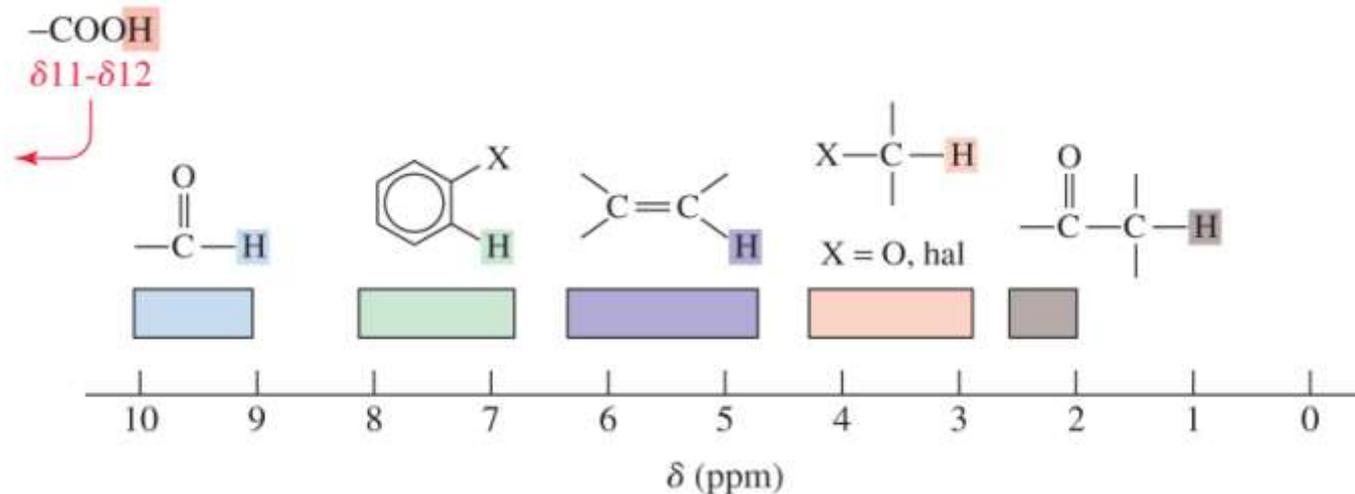
Fourier Transform NMR

- Radio-frequency pulse given.
- Nuclei absorb energy and precess (spin) like little tops.
- A complex signal is produced, then decays as the nuclei lose energy.
- Free induction decay (FID) is converted to spectrum.



Copyright © 2010 Pearson Prentice Hall, Inc.

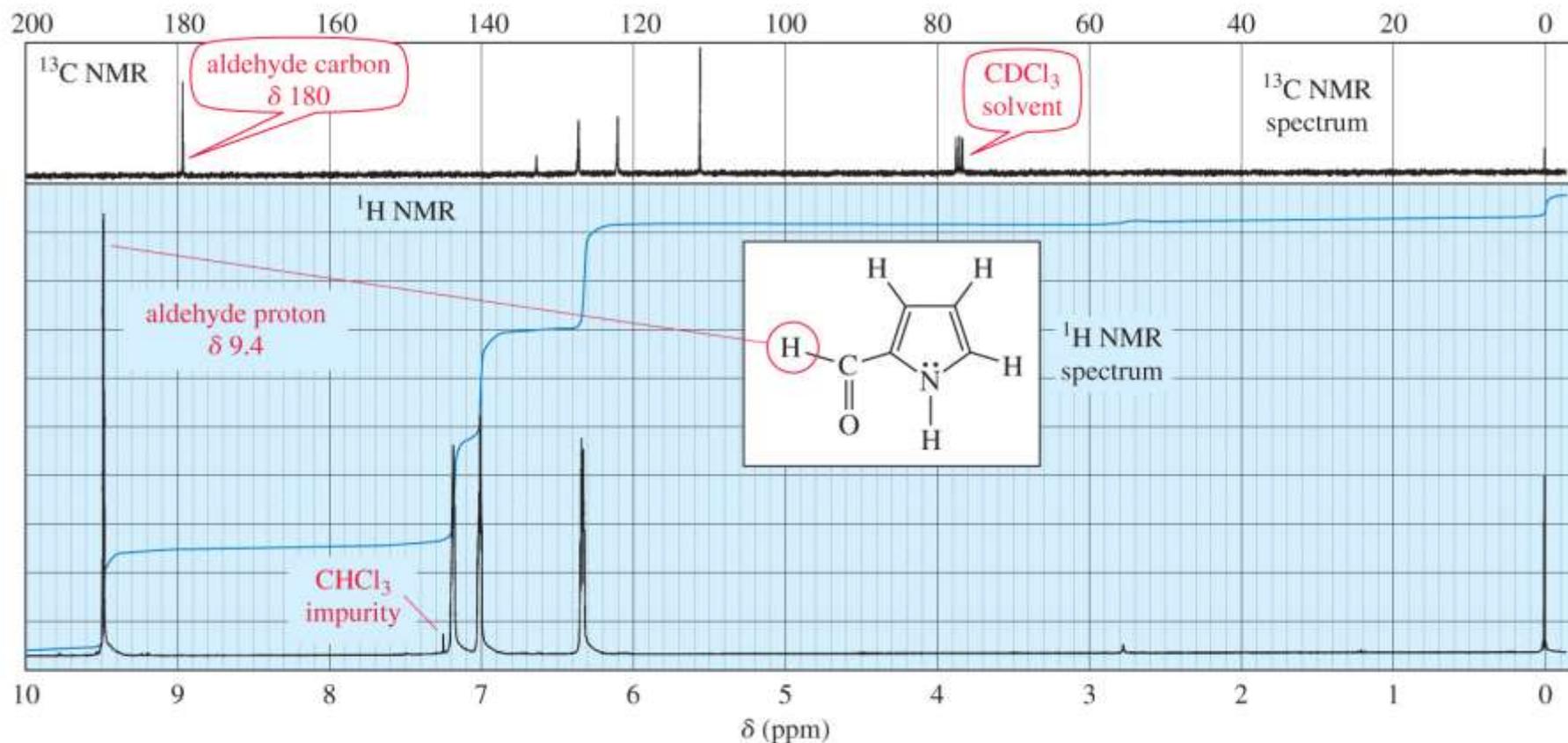
Carbon Chemical Shifts



Copyright © 2010 Pearson Prentice Hall, Inc.

- Table of approximate chemical shifts values for ^{13}C -NMR. Most of these values for a carbon atom are about 15–20 times the chemical shift of a proton if it were bonded to the carbon atom.

Combined ^{13}C and ^1H Spectra



Copyright © 2010 Pearson Prentice Hall, Inc.

Differences Between ^1H and ^{13}C Technique

- Resonance frequency is about one-fourth that of hydrogen, 15.1 MHz instead of 60 MHz.
- Peak areas are not proportional to number of carbons.
- Carbon atoms with more hydrogens absorb more strongly.

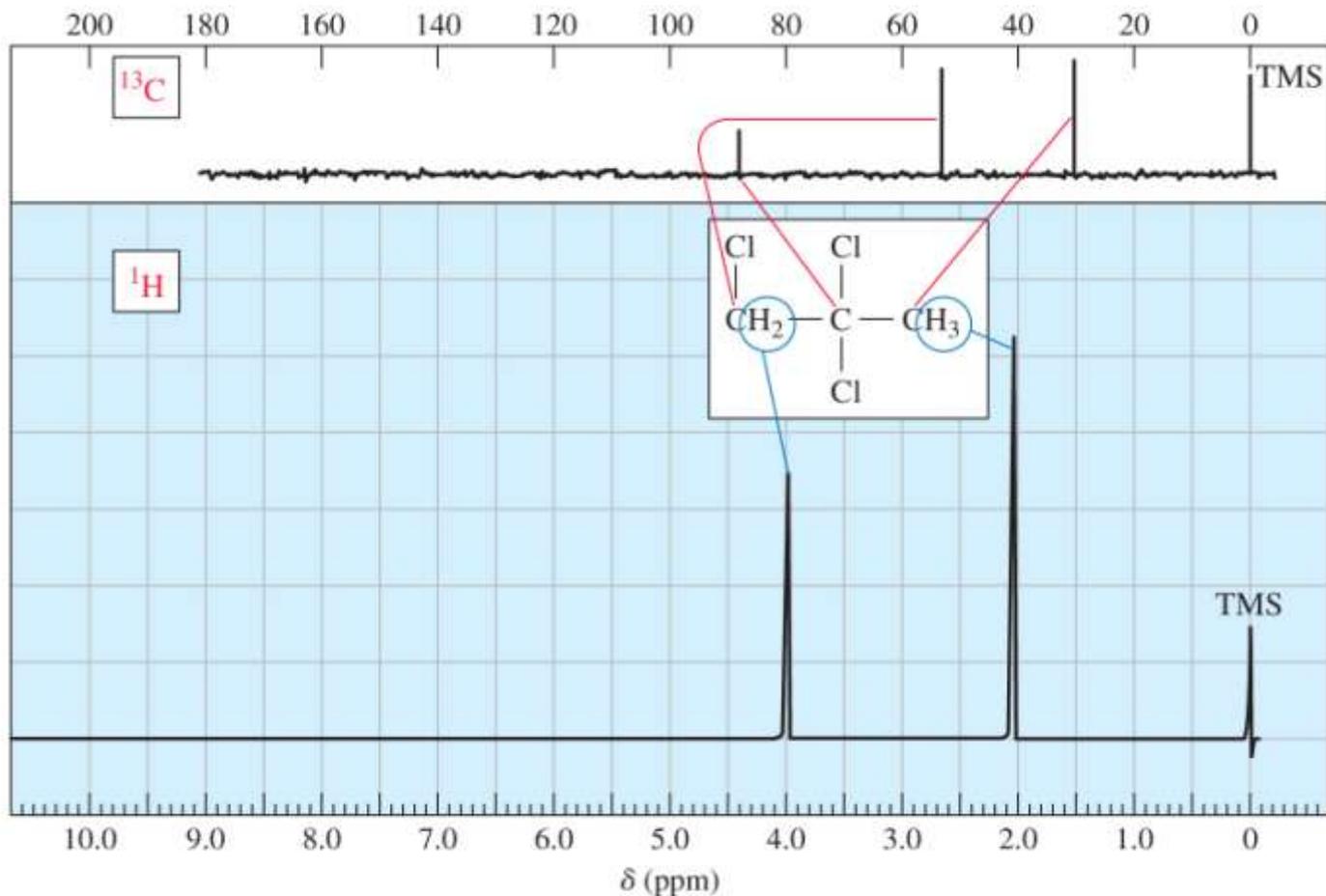
Spin-Spin Splitting

- It is unlikely that a ^{13}C would be adjacent to another ^{13}C , so splitting by carbon is negligible.
- ^{13}C will magnetically couple with attached protons and adjacent protons.
- These complex splitting patterns are difficult to interpret.

Proton Spin Decoupling

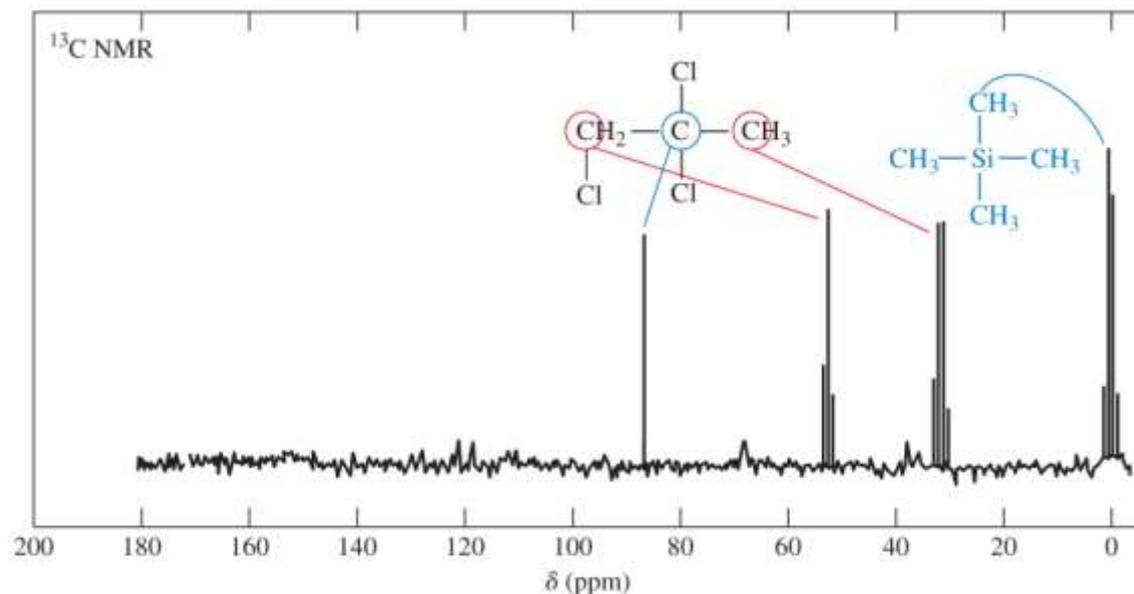
- To simplify the spectrum, protons are continuously irradiated with “noise,” so they are rapidly flipping.
- The carbon nuclei see an average of all the possible proton spin states.
- Thus, each different kind of carbon gives a single, unsplit peak because carbon-hydrogen splitting was eliminated.

^1H and ^{13}C -NMR of 1,2,2-Trichloropropane



Copyright © 2010 Pearson Prentice Hall, Inc.

Off-Resonance Decoupling



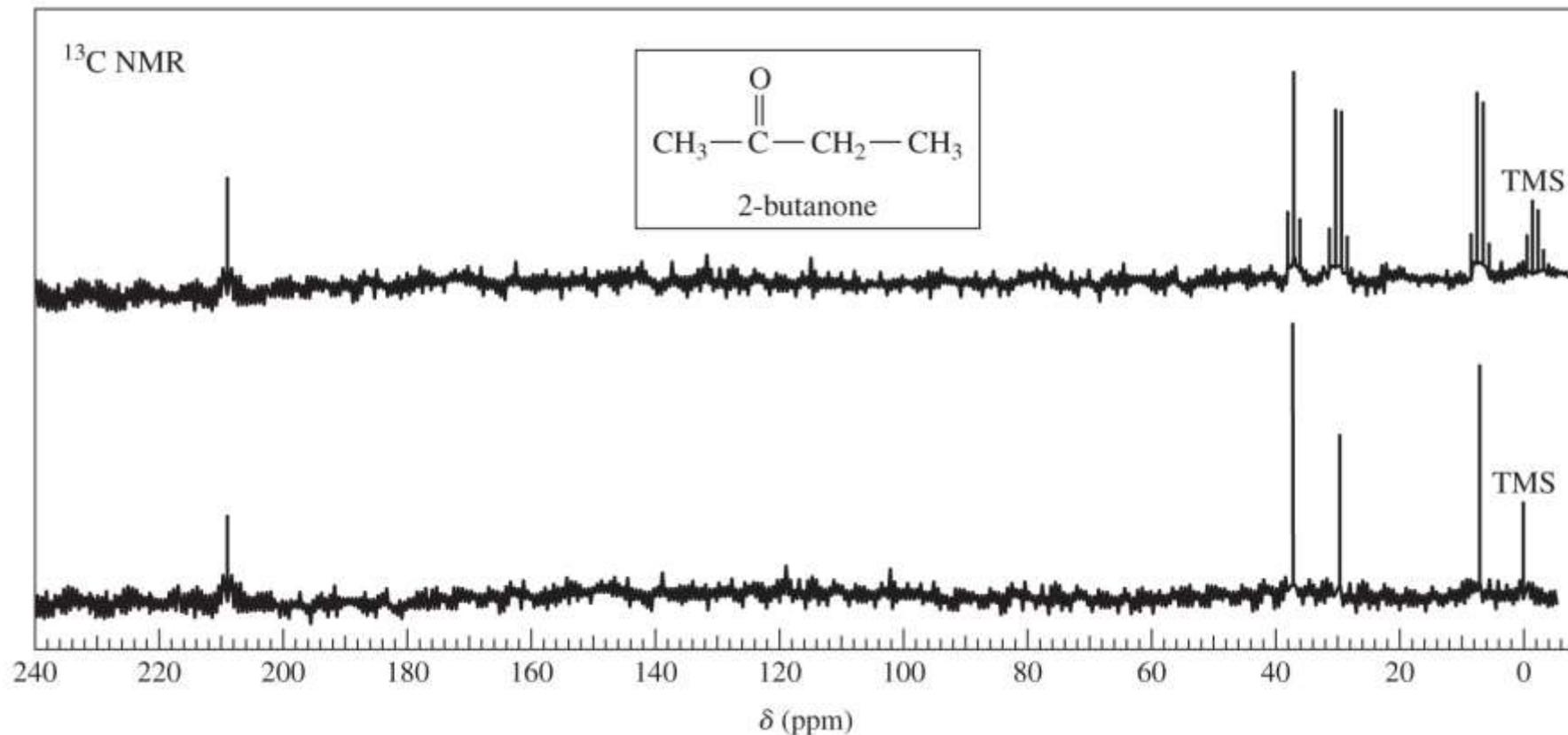
Copyright © 2010 Pearson Prentice Hall, Inc.

- ^{13}C nuclei are split only by the protons attached **directly** to them.
- The $N + 1$ rule applies: a carbon with N number of protons gives a signal with $N + 1$ peaks.

Interpreting ^{13}C NMR

- The number of different signals indicates the number of different kinds of carbon.
- The location (chemical shift) indicates the type of functional group.
- The peak area indicates the numbers of carbons (if integrated).
- The splitting pattern of off-resonance decoupled spectrum indicates the number of protons attached to the carbon.

Two ^{13}C NMR Spectra

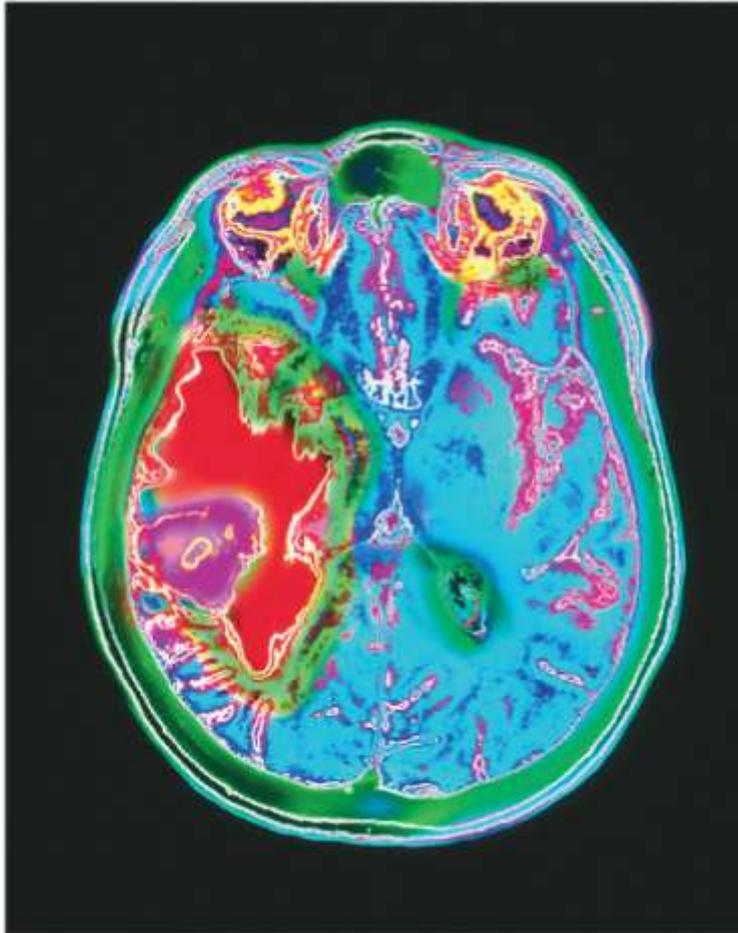


Copyright © 2010 Pearson Prentice Hall, Inc.

Magnetic Resonance Imaging (MRI)

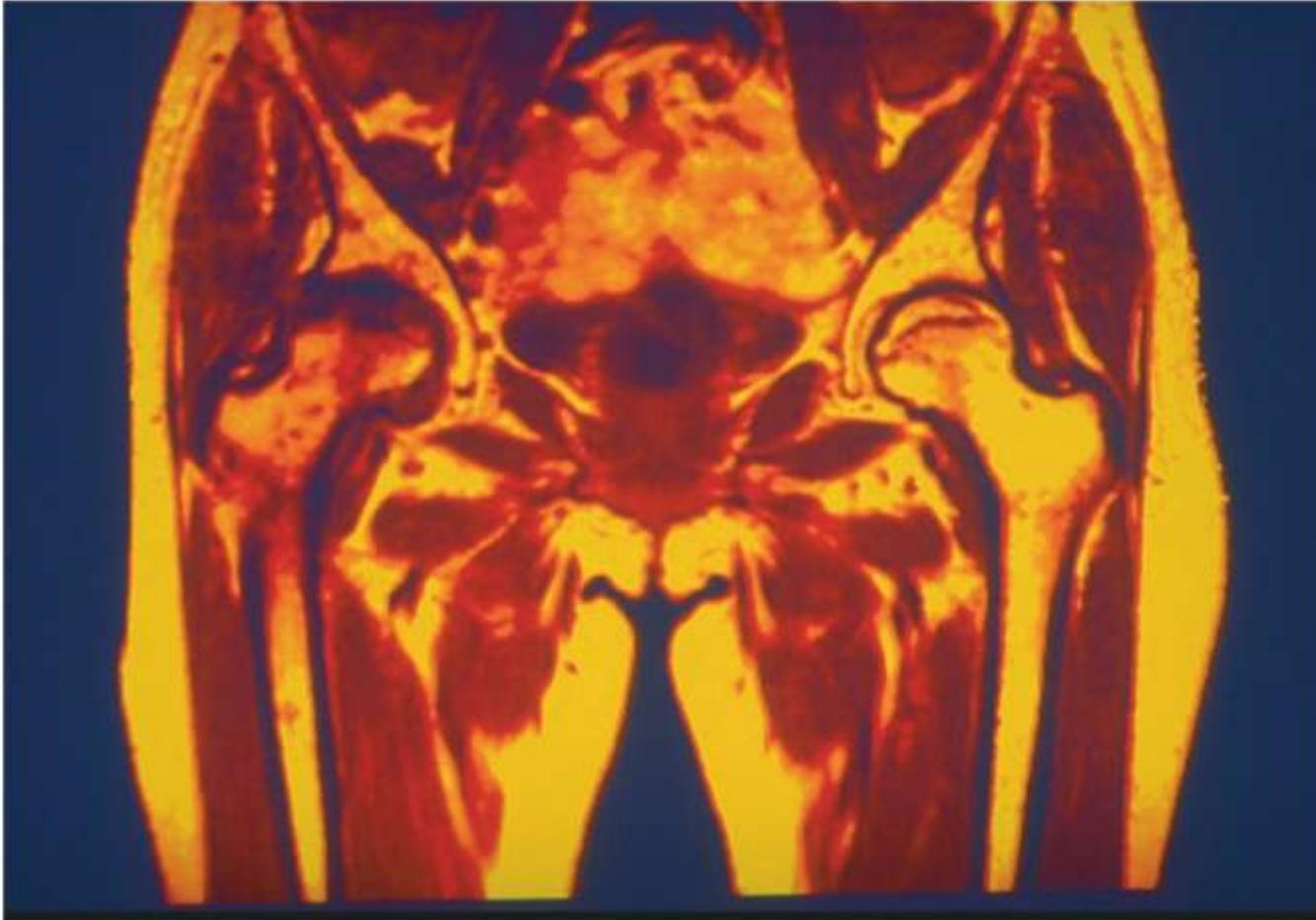
- Nuclear Magnetic Resonance Imaging is a noninvasive diagnostic tool.
- “Nuclear” is omitted because of public’s fear that it would be radioactive.
- Computer puts together “slices” to get 3-D images.
- Tumors are readily detected.

MRI Scan of a Human Brain



- MRI scan of a human brain showing a metastatic tumor in one hemisphere.

MRI Image of the Pelvic Region



Copyright © 2010 Pearson Prentice Hall, Inc.