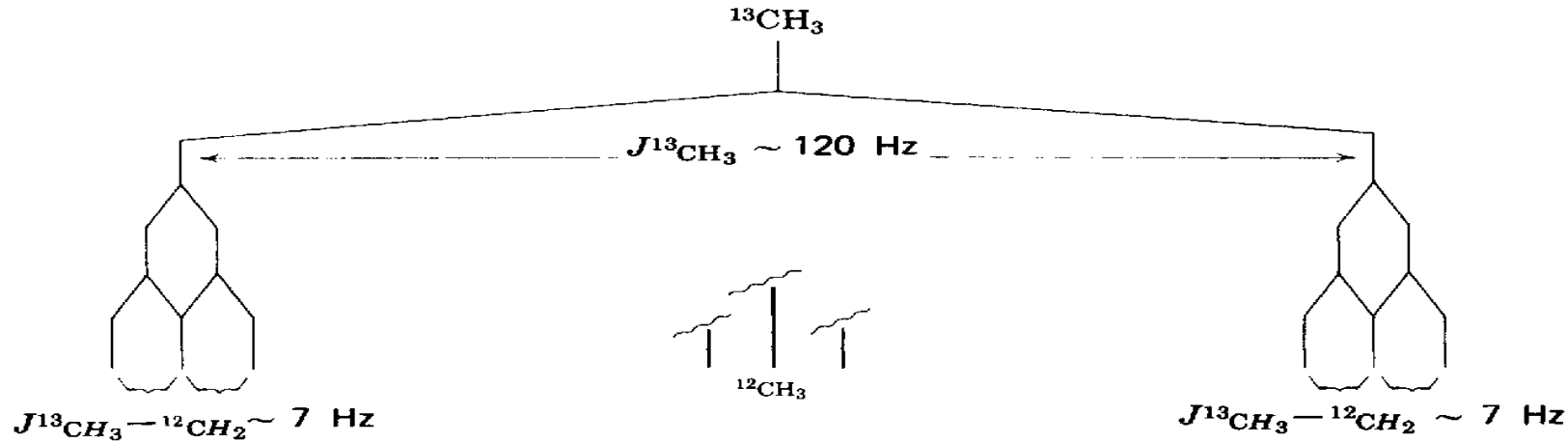
COUPLING OF PROTONS TO ^{13}C:

PART FOUR

The isotope ^{13}C has a natural abundance relative to ^{12}C of 1.1% and a spin number of $\frac{1}{2}$. Protons directly attached to ^{13}C are split into a doublet with a large coupling constant, about 115–270 Hz for ^{13}C—H. The

CH_3—CH_2 group, for example, is predominantly $^{12}CH_3$—$^{12}CH_2$ but contains a small amount of $^{13}CH_3$—$^{12}CH_2$ and of $^{12}CH_3$—$^{13}CH_2$. Thus, the $^{13}CH_3$ protons are split into a doublet by ^{13}C ($J \sim 120$ Hz), and each peak of the doublet is split into a triplet by the $^{12}CH_2$ protons ($J \sim 7$ Hz) as shown below. These "^{13}C

satellite" peaks are small because of the small number of molecules containing the $^{13}CH_3$ group and can usually be seen disposed on both sides of a large $^{12}CH_3$ peak (e.g., the large $^{12}CH_3$ triplet shown below). The chemical shift of the $^{12}CH_3$ protons is midway between the satellites. See Chapter 5 for ^{13}C NMR spectrometry.



Magnetic Resonance Imaging (MRI)

Like NMR spectroscopy, MRI takes advantage of the magnetic properties of certain nuclei, typically hydrogen, and of the signals emitted when those nuclei are stimulated by radiofrequency energy. Unlike what happens in NMR spectroscopy, though, MRI instruments use data manipulation techniques to look at the three-dimensional *location* of magnetic nuclei in the body rather than at the chemical nature of the nuclei. As noted, most MRI instruments currently look at hydrogen, present in abundance wherever there is water or fat in the body.

The signals detected by MRI vary with the density of hydrogen atoms and with the nature of their surroundings, allowing identification of different types of tissue and even allowing the visualization of motion. For example, the volume of blood leaving the heart in a single stroke can be measured, and heart motion can be observed. Soft tissues that don't show up well on X rays can be seen clearly, allowing diagnosis of brain tumors, strokes, and other conditions. The technique is also valuable in diagnosing damage to knees or other joints and is a noninvasive alternative to surgical explorations.

Several types of atoms in addition to hydrogen can be detected by MRI, and the applications of images based on ^{31}P atoms are being explored. The technique holds great promise for studies of metabolism.

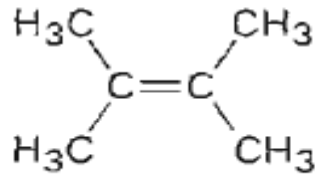
Predict the splitting patterns you would expect for each proton in the following molecules:

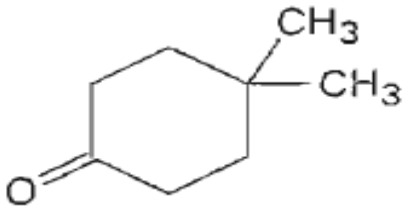
(a) $CHBr_2CH_3$ (b) $CH_3OCH_2CH_2Br$ (c) $ClCH_2CH_2CH_2Cl$

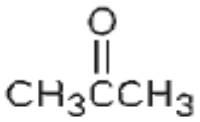
Draw structures for compounds that meet the following descriptions:

(a) C_2H_6O; one singlet (b) C_3H_7Cl; one doublet and one septet

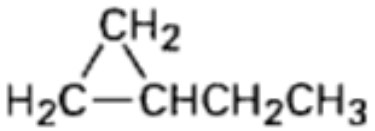
How many signals would you expect each of the following molecules to have in its ^1H and ^{13}C spectra?

(a) 

(b) 

(c) 

How could you use ^1H NMR to distinguish between the following pairs of isomers?

(a) $CH_3CH{=}CHCH_2CH_3$ and 

^{13}C NMR Spectrometry

The ^{12}C nucleus is not magnetically "active" (spin number, *I*, is zero), but the ^{13}C nucleus, like the ^{1}H nucleus, has a spin number of 1/2. However, since the

natural abundance is only 1.1%. Thus, only about 1 of every 100 carbons in organic sample is observed by NMR.

The problem of low abundance has been overcome by:

1. The use of signal averaging. (increases instrument sensitivity)
2. Fourier-transform NMR (FT-NMR) (increases instrument speed)

The earlier, continuous-wave, slow-scan procedure requires a large sample and a prohibitively long time to obtain a ^{13}C spectrum, but the availability of pulsed FT instrumentation, which permits simultaneous irradiation of all ^{13}C nuclei, has resulted in an increased activity in ^{13}C spectrometry, beginning in the early 1970's, comparable to the burst of activity in ^{1}H spectrometry that began in the late 1950's.

Characteristics of ^{13}C NMR Spectroscopy

Samples for ^{13}C spectrometry are usually dissolved in $CDCl_3$, and the ^{13}C peak of tetramethylsilane (TMS) is used as the internal reference.* A list of the common deuterated solvents is given in Appendix A. The scale is in δ units (ppm). The shifts in routine ^{13}C spectra range over about 240 ppm from TMS—about 20 times that of routine ^{1}H spectra (~ 12 ppm). As a result of the large range and the sharpness of the decoupled peaks, impurities are readily detected and mixtures may be readily analyzed. Even stereoisomers that are difficult to analyze by means of ^{1}H spectrometry usually show discrete ^{13}C peaks.

^{1}H and ^{13}C do split each other the same (n+1) rule is used so:

- Signals due to methyl groups become quartets - coupled to 3 hydrogens.
- methylene groups become triplets - coupled to 2 hydrogens.
- methine groups become doublets - coupled to 1 hydrogen.
- quaternary or carbonyl carbons remain singlets.

this splitting can b eliminated by adjusting the instrument.

- **The technique of removing the coupling of 1H to an attached carbon is called broadband (BB) proton decoupling.**
- **Most 13C NMR, therefore, consist of a single peak for each unique carbon**

Can we observe ^{13}C nuclei independent of ^{1}H nuclei?

Yes, because 13C nuclei absorb at a different frequency than 1H nuclei. Simply use a different Rf generator tuned to a different frequency

Why is spin-spin coupling between adjacent ^{13}C's not observed?

Since the natural abundance of this isotope is so low, the chance of finding two ^{13}C's next to each other is practically nil. However, if a compound were synthesized with only ^{13}C's, then coupling would be observed.

Most ^{13}C resonances are between 0 and 220 ppm downfield from the TMS reference line, with the exact chemical shift of each ^{13}C resonance dependent on that carbon's electronic environment within the molecule. Figure 13.7 shows the correlation of chemical shift with environment.

13C CHEMICAL SHIFTS

- Just as in 1H NMR spectroscopy, chemical shifts in 13C NMR depend on the electron density around the carbon nucleus
- Decreased electron density causes the signal to move downfield (deshielding)
- Increased electron density causes the signal to move up field (shielding)
- Because of the wide range of chemical shifts, it is rare to have two13C peaks coincidentally overlap

Some of the principal aspects of C NMR to consider that differ from H NMR are as follows:

- In the commonly used CPD or broadband proton-decoupled ^{13}C spectrum (see Section 4.2.1), the peaks are singlets unless the molecule contains other magnetically active nuclei such as ^{2}H, ^{31}P, or ^{19}F.
- The ^{13}C peaks are distributed over a larger chemical-shift range in comparison with the proton range.
- ^{13}C peak intensities do not correlate with the number of carbon atoms in a given peak in routine spectra, due to longer T_1 values and NOE.
- The ^{13}C nuclei are much less abundant and much less sensitive than protons. Larger samples and longer times are needed.
- For a given deuterated solvent, the ^{13}C and ^{1}H solvent peaks differ in multiplicities

- Factors determined the chemical shifts in13C-NMR:

1. Carbons chemical shift is effected by the electronegativity of nearby atoms.
2. Sp^3-hybridized carbons generally absorbed from 0 to 90 δ, while sp^2 carbons absorbed from 110 to 220.
3. Carbonyl carbons (C=O) are particularly distinct in ^{13}C NMR and always found at the low field end of the spectrum, from 160 to 180.

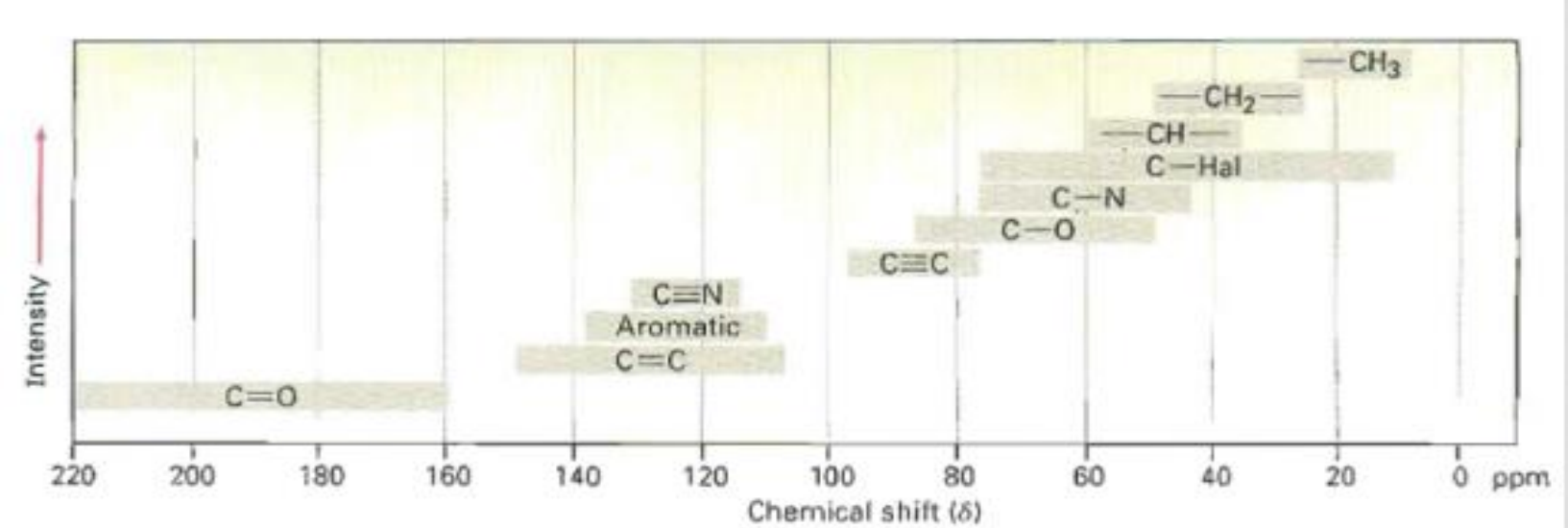
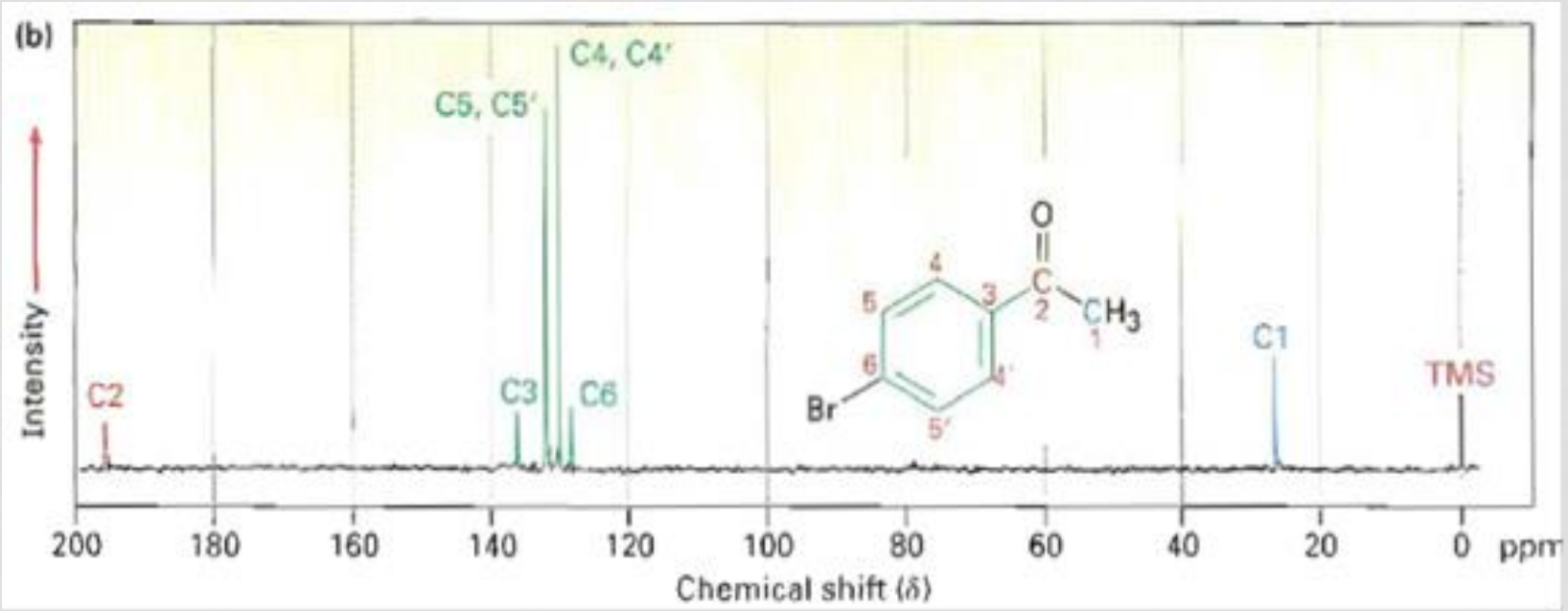


Figure 13.7 Chemical shift correlations for ^{13}C NMR.

particularly distinct in ^{13}C NMR and are always found at the low-field end of the spectrum, from 160 to 220 δ. Figure 13.8 shows the ^{13}C NMR spectra of 2-butanone and *para*-bromoacetophenone and indicates the peak assignments. Note that the C=O carbons are at the left edge of the spectrum in each case.



^{1}H Decoupling Techniques

As mentioned in Section 3.7.5, the ^{13}C nucleus does not show coupling in ^{1}H NMR spectra (except for ^{13}C satellites) due to the low natural abundance of ^{13}C (1.1%); however, the same cannot be said about the reverse. The ^{1}H nucleus is >99% in natural abundance and effectively couples to the ^{13}C nuclei. Because of the large $^{1}J_{CH}$ values for $^{13}C—^{1}H$ (~110–320 Hz) and appreciable $^{2}J_{CH}$, $^{3}J_{CH}$ values for $^{13}C—C—^{1}H$ and $^{13}C—C—C—^{1}H$ (~0–60 Hz) couplings, proton-coupled ^{13}C spectra usually show complex overlapping multiplets that are difficult to interpret (Figure 4.1a); the proton-coupled spectrum of choles-