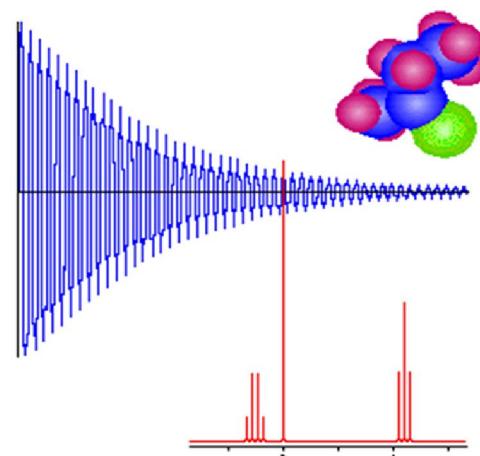


Nuclear Magnetic Resonance (NMR) Spectroscopy



Definition of NMR Spectroscopy

Nuclear magnetic resonance spectroscopy:
commonly referred to as NMR, is a technique
which exploits the magnetic properties of
certain nuclei to study physical, chemical, and
biological properties of matter



Spin of Nuclei

Fermions : Odd mass nuclei with an odd number of nucleons have fractional spins.

$I = 1/2$ (1H , ^{13}C , ^{19}F , ^{31}P), $I = 3/2$ (^{11}B , ^{33}S) & $I = 5/2$ (^{17}O).

Bosons : Even mass nuclei with odd numbers of protons and neutrons have integral spins.

$I = 1$ (2H , ^{14}N)

Even mass nuclei composed of even numbers of protons and neutrons have zero spin

$I = 0$ (^{12}C , and ^{16}O , ^{32}S)

Magnetic Momentum

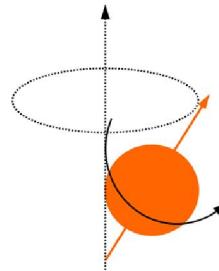
A spinning charge generates a magnetic field, the resulting spin-magnet has a magnetic moment (μ) proportional to the spin I

magnetic moment μ

$$\mu = \gamma \sqrt{I(I+1)} h / 2\pi \quad \text{When } I=0, \mu=0$$

where γ is the gyromagnetic ratio,
and it is a constant for a given nucleus

** There is no spin for nuclei with $I=0$

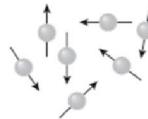


Energy Differentiation

A spinning proton creates a magnetic field.

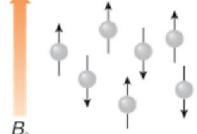


With no external magnetic field...



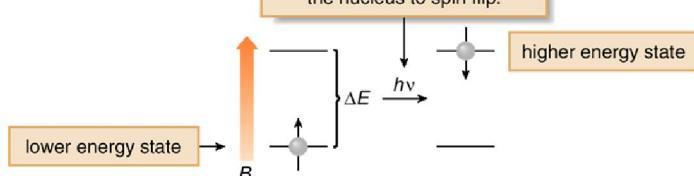
The nuclear magnets are randomly oriented.

In a magnetic field...



The nuclear magnets are oriented with or against B_0 .

Absorbing RF radiation causes the nucleus to spin flip.

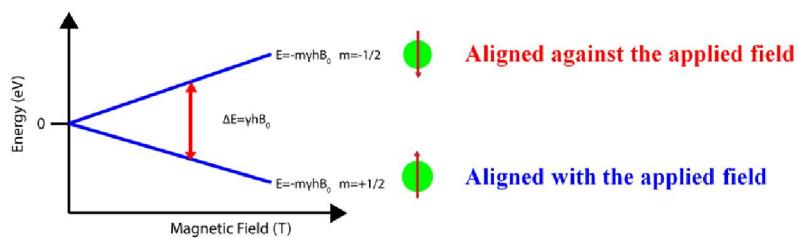


A nucleus is in resonance when it absorbs RF radiation and “spin flips” to a higher energy state.

Energy Differentiation

In the presence of an external magnetic field (\mathbf{B}_0), two spin states exist, $+1/2$ and $-1/2$ (For $I=1/2$).

The magnetic moment of the lower energy $+1/2$ state is aligned with the external field, and that of the higher energy $-1/2$ spin state is opposed to the external field.



Energy Differentiation

Difference in energy between the two states is given by:

$$\Delta E = \gamma h B_o / 2\pi$$

where:

B_o – external magnetic field

h – Planck's constant

γ – gyromagnetic ratio

When the energy of the photon matches the energy difference between the two spin states , an absorption of energy occurs. We call that phenomenon *Resonance*

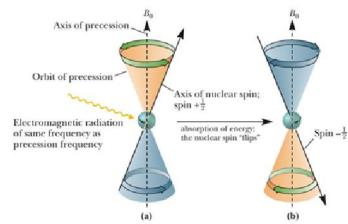
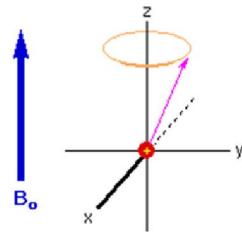
$$\Delta E = hv = \gamma h B_o / 2\pi \quad \text{So, } v = \gamma B_o / 2\pi$$

Larmor Precession

Spinning particle precesses about the external field axis with an angular frequency known as the Larmor frequency

$$\omega_L = \gamma B_0$$

When radio frequency energy matching the Larmor frequency is introduced at a right angle to the external field, it would cause a transition between the two energy levels of the spin. In other world, the precessing nucleus will absorb energy and the magnetic moment will flip to its $I = -1/2$ state



Brown/Faure/Iverson
Organic Chemistry 5e
Figure 13.03

Date: 07/06/07

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γ - Values for some nuclei

Isotope	Net Spin	$\gamma / \text{MHz T}^{-1}$	Abundance / %
^1H	1/2	42.58	99.98
^2H	1	6.54	0.015
^3H	1/2	45.41	0.0
^{31}P	1/2	17.25	100.0
^{23}Na	3/2	11.27	100.0
^{14}N	1	3.08	99.63
^{15}N	1/2	4.31	0.37
^{13}C	1/2	10.71	1.108
^{19}F	1/2	40.08	100.0

Larmor frequencies vs B_0

	^1H	^{13}C
γ	42.58	10.71
T	ω_L (MHz)	ω_L (MHz)
1.409	60	15.1
4.697	200	50.3
6.341	270	67.9
9.394	400	100.6
14.091	600	150.9
21.137	900	226.4

Increasing B_0 , Larmor frequency increases.

NMR Spectrometer

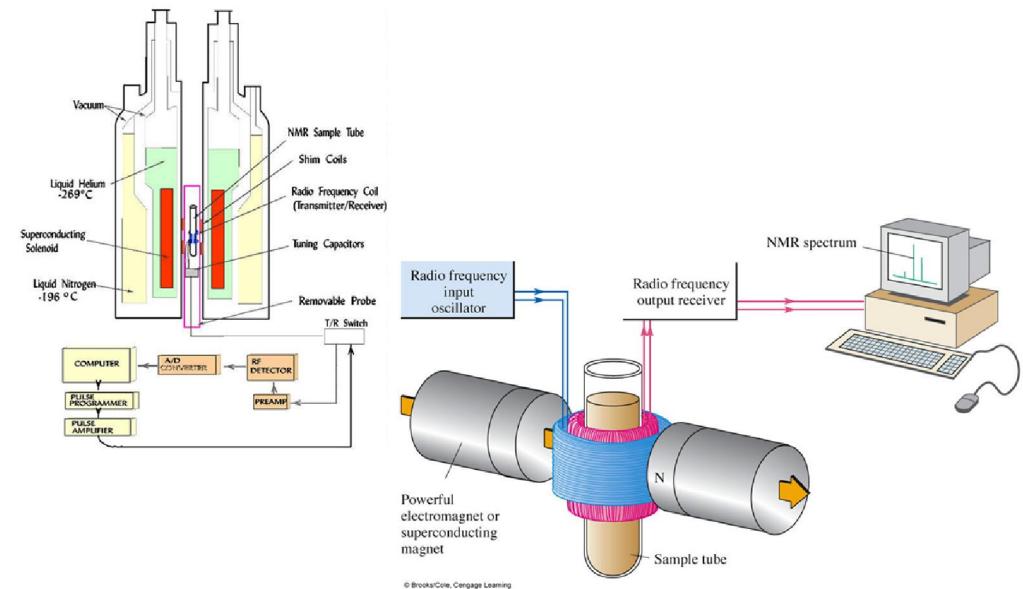


200 MHz
 $B_0 = 4.70\text{ T}$

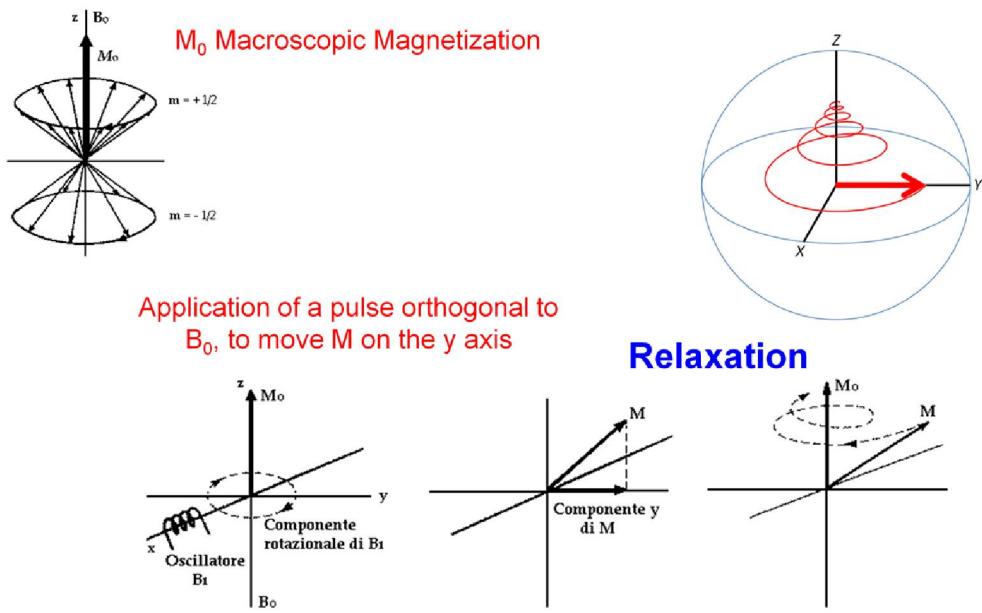


900 MHz
 $B_0 = 21.1\text{ T}$

Schematic NMR Spectrometer

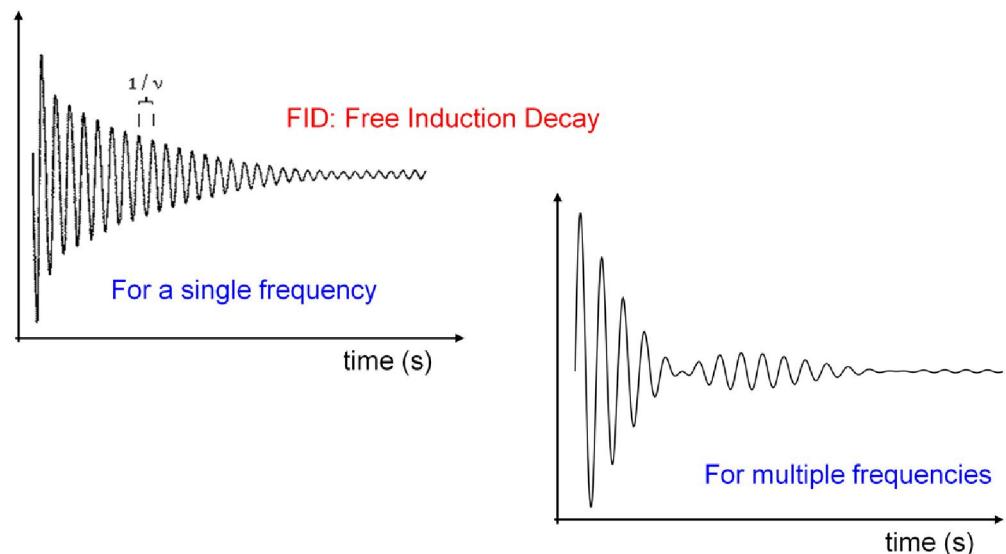


Production of NMR Signal

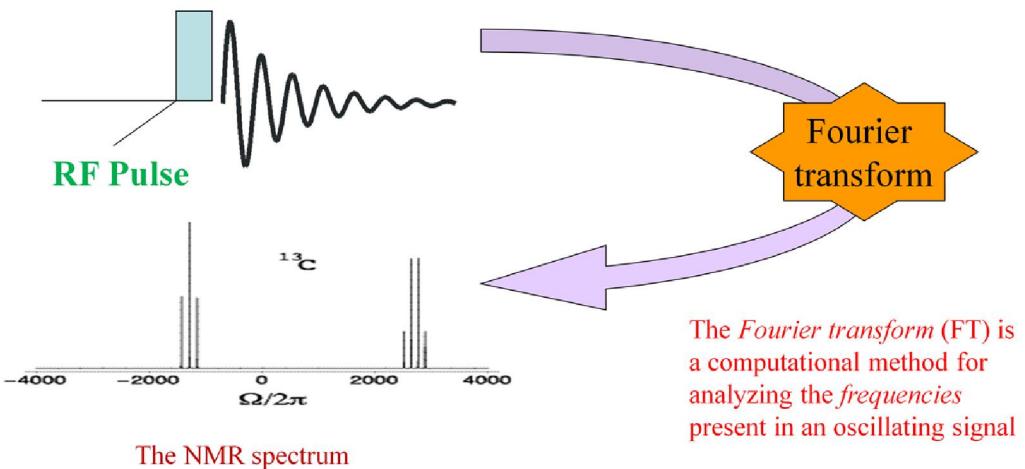


Production of NMR Signal

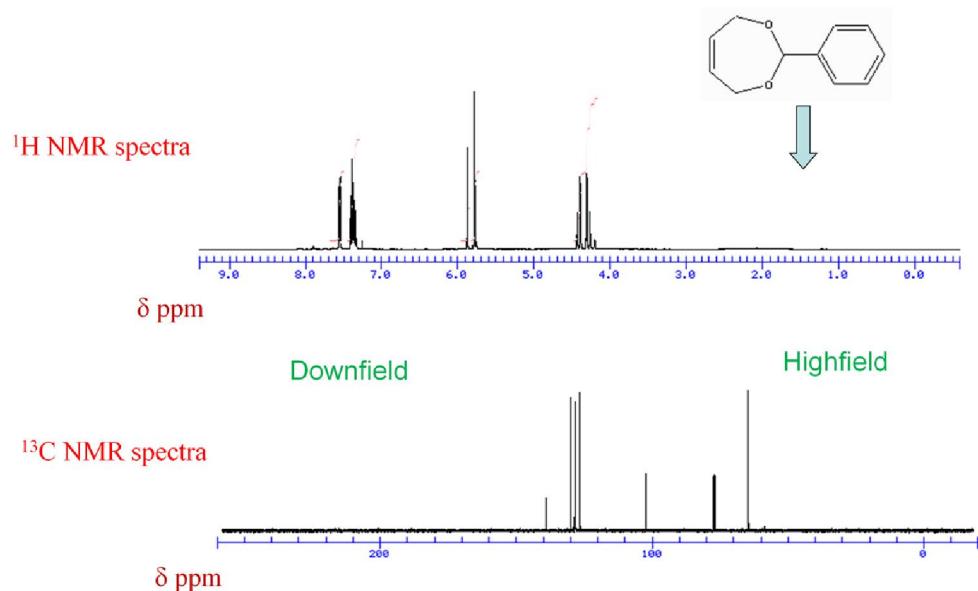
During relaxation, energy is emitted by the nuclei and is revealed by a receiving coil, revealing a trace oscillating with the Larmor frequency of the nucleus.



Fourier transformation and the NMR spectrum



^1H NMR and ^{13}C NMR Spectrum

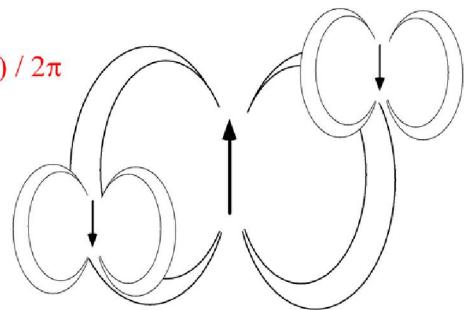


Chemical Shift - δ

When an atom is placed in a magnetic field, its electrons circulate about the direction of the applied magnetic field. This circulation causes a small magnetic field at the nucleus which opposes the externally applied field

The magnetic field at the nucleus (the effective field) is therefore generally less than the applied field by a fraction :

$$B = B_0 (1-\sigma) \quad \text{so} \quad v = \gamma B_0 (1-\sigma) / 2\pi$$



Chemical Shift - δ

The electron density around each nucleus in a molecule varies according to the types of nuclei and bonds in the molecule. The opposing field and therefore the effective field at each nucleus will vary. This is called the chemical shift phenomenon.

As we can tell from $v = \gamma B_0 (1-\sigma) / 2\pi$, the greater the value of B_0 , the greater the frequency difference.

This relationship could make it difficult to compare NMR spectra taken on spectrometers operating at different field strengths.

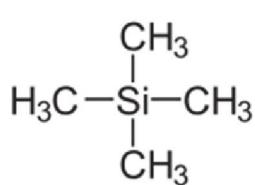
The term chemical shift was developed to avoid this problem. The chemical shift of a nucleus is the difference between the resonance frequency of the nucleus and a standard, relative to the standard. This quantity is reported in ppm and given the symbol delta.

$$\delta = \frac{v - v_{REF}}{v_{REF}} * 10^6$$

Standard for Chemical Shift

In NMR spectroscopy, the standard is often tetramethylsilane, $\text{Si}(\text{CH}_3)_4$, abbreviated TMS.

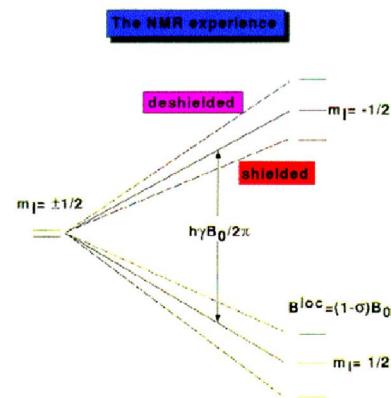
Tetramethyl silane (TMS) is used as reference because it is soluble in most organic solvents, is inert, volatile, and has 12 equivalent ^1H and 4 equivalent ^{13}C . TMS signal is set to 0



Shielding and Deshielding

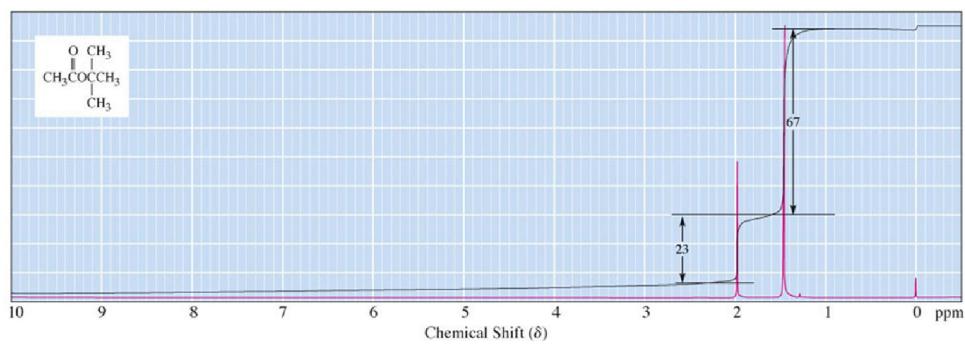
A nucleus is said to be **shielded** when electrons around the nucleus circulates in a magnetic field and create a secondary induced magnetic field which opposes the applied field.

Trends in chemical shift are explained based on the degree of shielding or deshielding , e.g. of deshielding effect

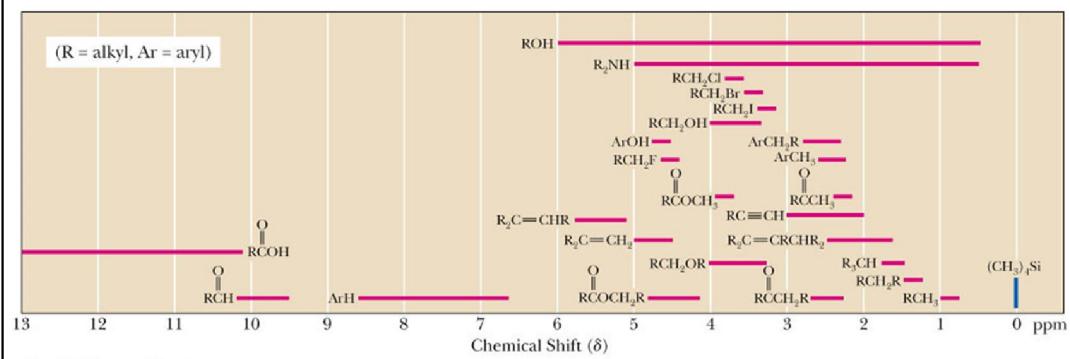


¹H-NMR

- ¹H experiencing the same chemical environment or chemical shift are called equivalent hydrogens.
- ¹H experiencing different environment or having different chemical shifts are nonequivalent hydrogens.



Chemical Shift - $^1\text{H-NMR}$



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¹H Chemical shifts

Type of Hydrogen	Chemical Shift (δ)	Type of Hydrogen	Chemical Shift (δ)
(CH ₃) ₄ Si	0 (by definition)	O	
RC ₂ H ₃	0.8-1.0	RC(=O)CH ₃	3.7-3.9
RC ₂ H ₂ R	1.2-1.4	O	
R ₃ CH	1.4-1.7	RC(=O)CH ₂ R	4.1-4.7
R ₂ C=CRC ₂ H ₂ R ₂	1.6-2.6	RC ₂ I	3.1-3.3
RC≡CH	2.0-3.0	RC ₂ Br	3.4-3.6
ArCH ₃	2.2-2.5	RC ₂ Cl	3.6-3.8
ArCH ₂ R	2.3-2.8	RC ₂ F	4.4-4.5
ROH	0.5-6.0	ArOH	4.5-4.7
RC ₂ OH	3.4-4.0	R ₂ C=C ₂ H ₂	4.6-5.0
RC ₂ OR	3.3-4.0	R ₂ C=C ₂ HR	5.0-5.7
R ₂ NH	0.5-5.0	ArH	6.5-8.5
O		O	
RC(=O)CH ₃	2.1-2.3	RC(=O)H	9.5-10.1
O		O	
RC(=O)CH ₂ R	2.2-2.6	RCOOH	10-13

Chemical Shift- δ

Chemical shift depends on :

- Electronegativity of nearby atoms
- Hybridization of adjacent atoms
- diamagnetic effects
- paramagnetic effects
- solvent effect

Factors to Affect ^1H Chemical Shift

Chemical shift : (1) electronegativity of nearby atoms, (2) hybridization of adjacent atoms, and (3) diamagnetic effects

Electronegativity

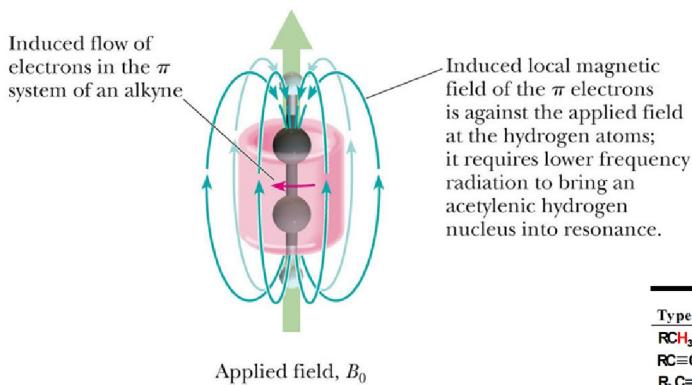
$\text{CH}_3\text{-X}$	Electron eg- ativity of X	Chemical Shift (δ)
CH_3F	4.0	4.26
CH_3OH	3.5	3.47
CH_3Cl	3.1	3.05
CH_3Br	2.8	2.68
CH_3I	2.5	2.16
$(\text{CH}_3)_4\text{C}$	2.1	0.86
$(\text{CH}_3)_4\text{Si}$	1.8	0.00

Hybridization of adjacent atoms

Type of Hydrogen (R = alkyl)	Name of Hydrogen	Chemical Shift (δ)
RCH_3 , R_2CH_2 , R_3CH	Alkyl	0.8 - 1.7
$\text{R}_2\text{C}=\text{C}(\text{R})\text{CHR}_2$	Allylic	1.6 - 2.6
$\text{RC}\equiv\text{CH}$	Acetylenic	2.0 - 3.0
$\text{R}_2\text{C}=\text{CHR}$, $\text{R}_2\text{C}=\text{CH}_2$	Vinylic	4.6 - 5.7
RCHO	Aldehydic	9.5-10.1

Carbon-Carbon Triple Bond Effect

A carbon-carbon triple bond shields an acetylenic hydrogen and shifts its signal to lower frequency (to the right) to a smaller value

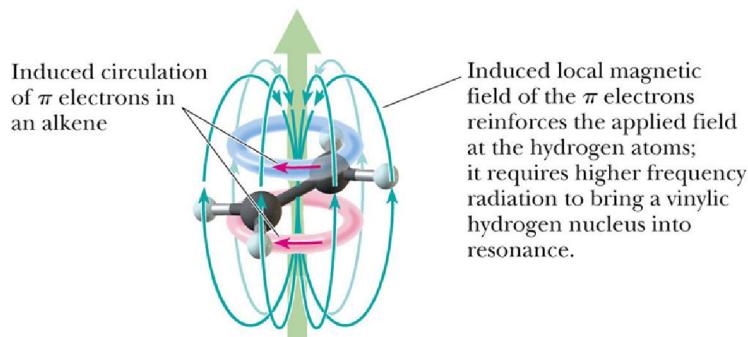


Type of H	Name	Chemical Shift (δ)
RCH_3	Alkyl	0.8 - 1.0
$\text{RC}\equiv\text{CH}$	Acetylenic	2.0 - 3.0
$\text{R}_2\text{C}=\text{CH}_2$	Vinylic	4.6 - 5.7

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Carbon-Carbon Double Bond Effect

Magnetic induction in the p bond of a carbon-carbon double bond deshields vinylic hydrogens and shifts their signal higher frequency

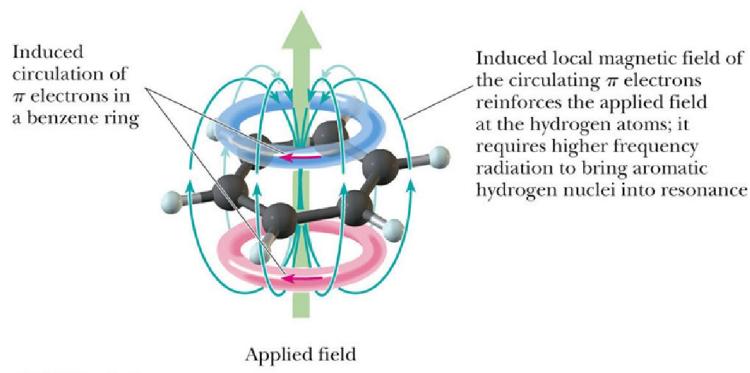


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Type of H	Name	Chemical Shift (δ)
RCH_3	Alkyl	0.8 - 1.0
$\text{RC}\equiv\text{CH}$	Acetylenic	2.0 - 3.0
$\text{R}_2\text{C}=\text{CH}_2$	Vinylic	4.6 - 5.7

Aromatic Effect

The magnetic field induced by circulation of p electrons in an aromatic ring deshields the hydrogens on the ring and shifts their signal to higher frequency



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Spin-Spin Coupling

Spin-spin coupling:

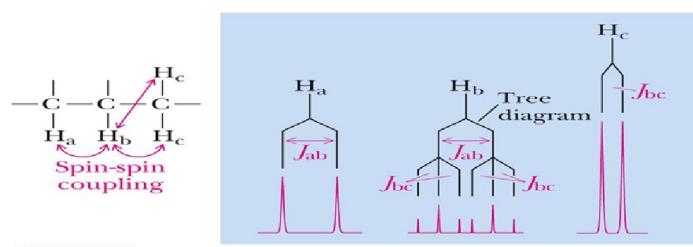
The coupling of the intrinsic angular momentum of different particles. Such coupling between pairs of nuclear spins is an important feature of [nuclear magnetic resonance](#) (NMR) spectroscopy as it can provide detailed information about the structure and conformation of molecules. Spin-spin coupling between nuclear spin and electronic spin is responsible for [hyperfine structure](#) in atomic spectra.

J-Coupling

***J*-coupling:**

also called *indirect spin-spin coupling*, is the coupling between two nuclear spins due to the influence of bonding electrons on the magnetic field running between the two nuclei. *J*-coupling provides information about dihedral angles, which can be estimated using the Karplus equation. It is an important observable effect in 1D NMR spectroscopy.

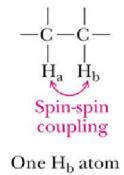
The coupling constant, *J* (usually in frequency units, Hz) is a measure of the interaction between a pair of nuclei



Coupling constant

Coupling constant (J):

The separation on an NMR spectrum (in hertz) between adjacent peaks in a multiplet.

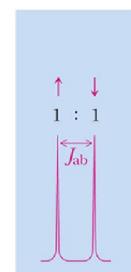


One H_b atom

$$^nJ_{a,b} = \frac{\Delta\delta}{10^6} * v_{REF}$$

n order on the coupling constant:
 number of C atoms between the 2 H atoms

a,b H atoms interacting with that J



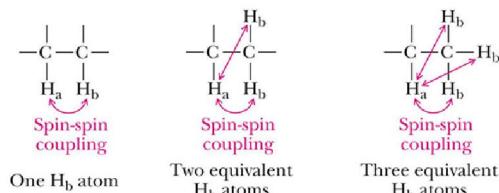
For equivalent H

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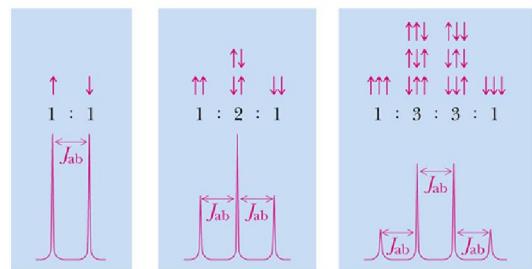
Coupling constant

Coupling constant (J):

The separation on an NMR spectrum (in hertz) between adjacent peaks in a multiplet.



For equivalent H



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Signal Splitting for ^1H

Peak:

The units into which an NMR signal is split; doublet, triplet, quartet, multiplet, etc.

Signal splitting:

Splitting of an NMR signal into a set of peaks by the influence of neighboring nonequivalent hydrogens.

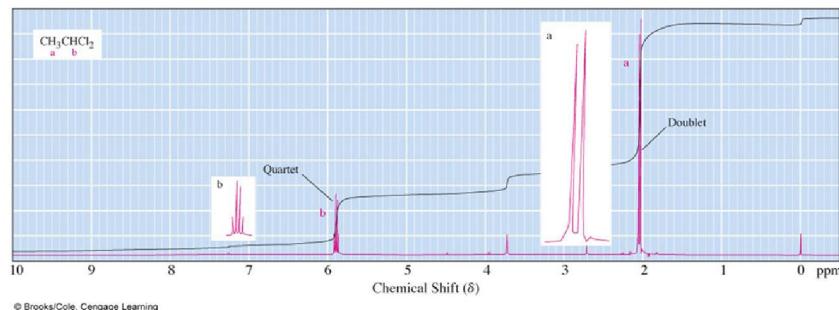
($n + 1$) rule:

If a hydrogen has n hydrogens nonequivalent to it but equivalent among themselves on the same or adjacent atom(s), its $^1\text{H-NMR}$ signal is split into $(n + 1)$ peaks.

Pascal's triangle

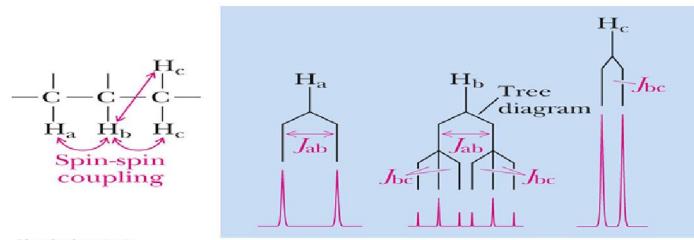
The relative peak intensities for multiplet peaks arising from J -coupling of a ^1H to N equivalent ^1H can be determined using Pascal's triangle:

$n = 0$	1
$n = 1$	1 1
$n = 2$	1 2 1
$n = 3$	1 3 3 1
$n = 4$	1 4 6 4 1



Coupling constant

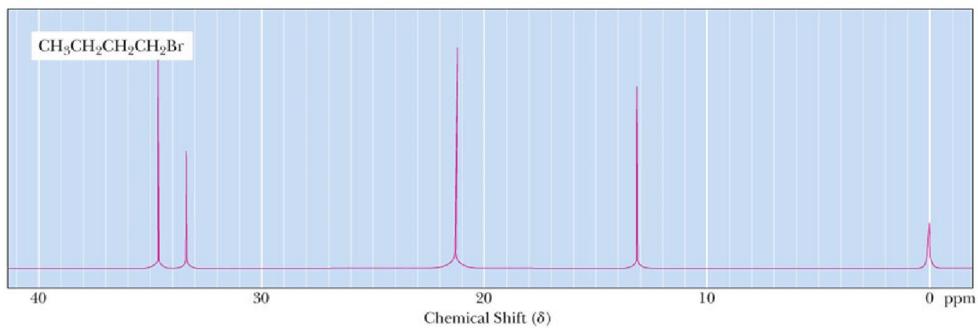
For non equivalent H



A complex signal is obtained, as a result of different coupling constants between the HH couples.

¹³C-NMR Spectroscopy

Organic compounds contain carbon. Unfortunately, the C-12 nucleus does not have a nuclear spin, but the C-13 nucleus does due to the presence of an unpaired neutron. C-13 nuclei make up approximately 1% of the carbon nuclei on earth. Therefore, ¹³C NMR will be much less sensitive than ¹H NMR.



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¹³C-NMR Spectroscopy

The presence of spin-spin coupling between a ¹³C nucleus and the nuclei of ¹H atoms bonded to the ¹³C, splits the carbon-13 peaks and causes an even poorer signal-to-noise ratio

Each nonequivalent ¹³C gives a different signal

A ¹³C signal is split by the ¹H bonded to it according to the $(n + 1)$ rule.

Coupling constants of 100-250 Hz are common, which means that there is often significant overlap between signals, and splitting patterns can be very difficult to determine.

The most common mode of operation of a ¹³C-NMR spectrometer is a proton-decoupled mode.

Decoupling

proton-decoupled mode,

A sample is irradiated with two different radiofrequencies. One to excite all ^{13}C nuclei, a second to cause all protons in the molecule to undergo rapid transitions between their nuclear spin states.

On the time scale of a ^{13}C -NMR spectrum, each proton is in an average or effectively constant nuclear spin state, with the result that ^1H - ^{13}C spin-spin interactions are not observed and they are **decoupled**.

As a result, ^{13}C -NMR spectrum contains a peak for each non equivalent carbon within the molecule.

Chemical Shift - ^{13}C -NMR

Characteristic Carbon NMR Chemical Shifts (ppm)					
$(\text{CH}_3)_4\text{Si} = \text{TMS} = 0.00 \text{ ppm (singlet)}$					$\text{CDCl}_3 \text{ (solvent)} = 77.0 \text{ ppm (triplet)}$
RCH_3	0 – 40	RCH_2Cl	35 – 80	benzene ring	110 – 160
RCH_2R	15 – 55	R_3COH	40 – 80	C=O ester	160 – 180
R_3CH	20 – 60	R_3COR	40 – 80	C=O amide	165 – 180
RCH_2l	0 – 40	$\text{RC}\equiv\text{CR}$	65 – 85	C=O carboxylic acid	175 – 185
RCH_2Br	25 – 65	$\text{R}_2\text{C=CR}_2$	100 - 150	C=O aldehyde, ketone	180 – 210

Trends

- $\text{RCH}_3 < \text{R}_2\text{CH}_2 < \text{R}_3\text{CH}$
- Electronegative atoms cause downfield shift
- Pi bonds cause downfield shift
- C=O 160-210 ppm

^{13}C -NMR: Integration

$^1\text{H-NMR}$: Integration reveals relative number of hydrogens per signal

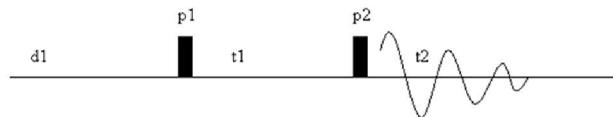
$^{13}\text{C-NMR}$: Integration reveals relative number of carbons per signal

- Rarely useful due to slow relaxation time for ^{13}C

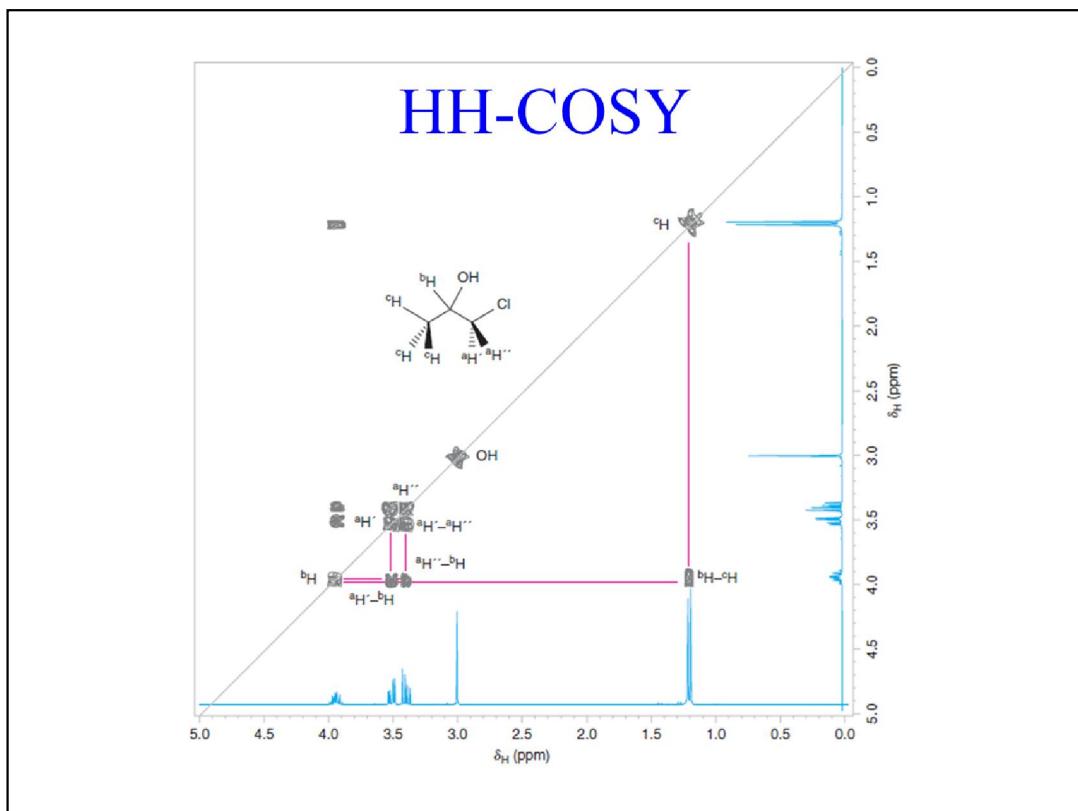
↓
time for nucleus to relax from
excited spin state to ground state

2D-NMR

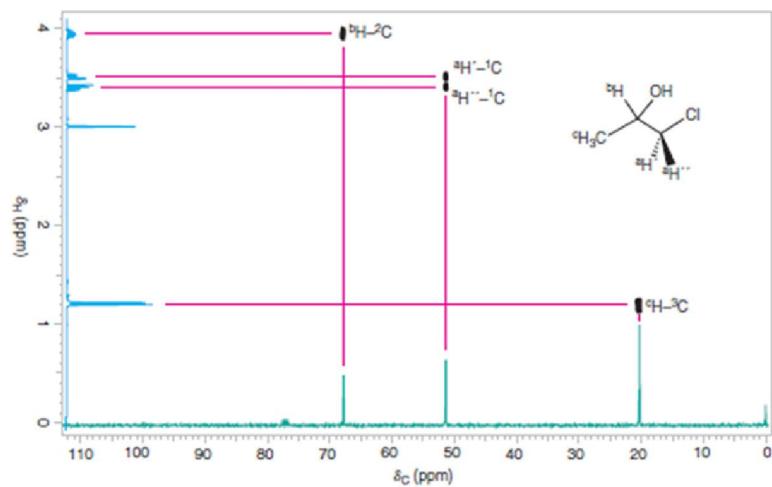
Following an opportune combination of RF pulses and resting time before measurements, it is possible to obtain **magnetization transfer** from an atom to another one, in close proximity.



This technique is called COrellation SpectroscopY or COSY.
Magnetization transfer can be obtained between atoms of the same type (^1H - ^1H) or between different atoms (^1H - ^{13}C).



HC-COSY



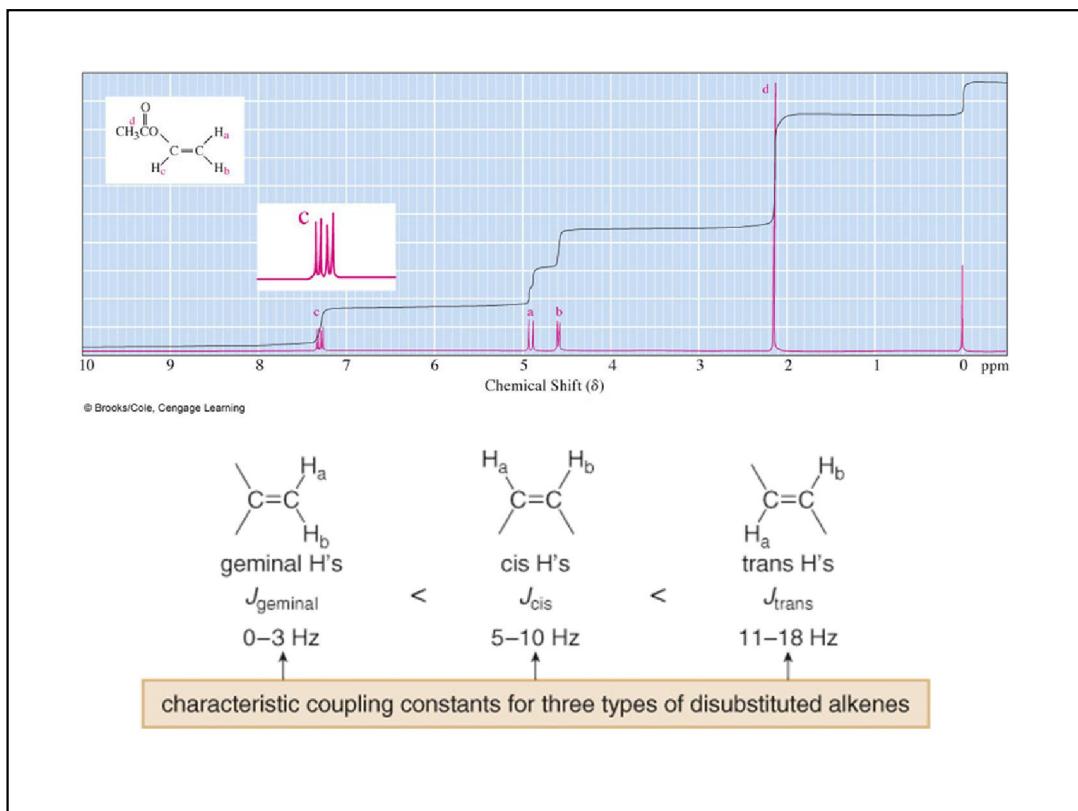
Interpreting NMR Spectra

Alkanes

^1H -NMR signals appear in the range of 0.8-1.7,
 ^{13}C -NMR signals appear in the considerably wider range of 10-60.

Alkenes

^1H -NMR signals appear in the range 4.6-5.7.
 ^1H -NMR coupling constants are generally larger for *trans*-vinylic hydrogens ($J=11\text{-}18\text{ Hz}$) compared with *cis*-vinylic hydrogens ($J=5\text{-}10\text{ Hz}$).
 ^{13}C -NMR signals for sp^2 hybridized carbons appear in the range 100-160, which is to higher frequency from the signals of sp^3 hybridized carbons.



Interpreting NMR Spectra

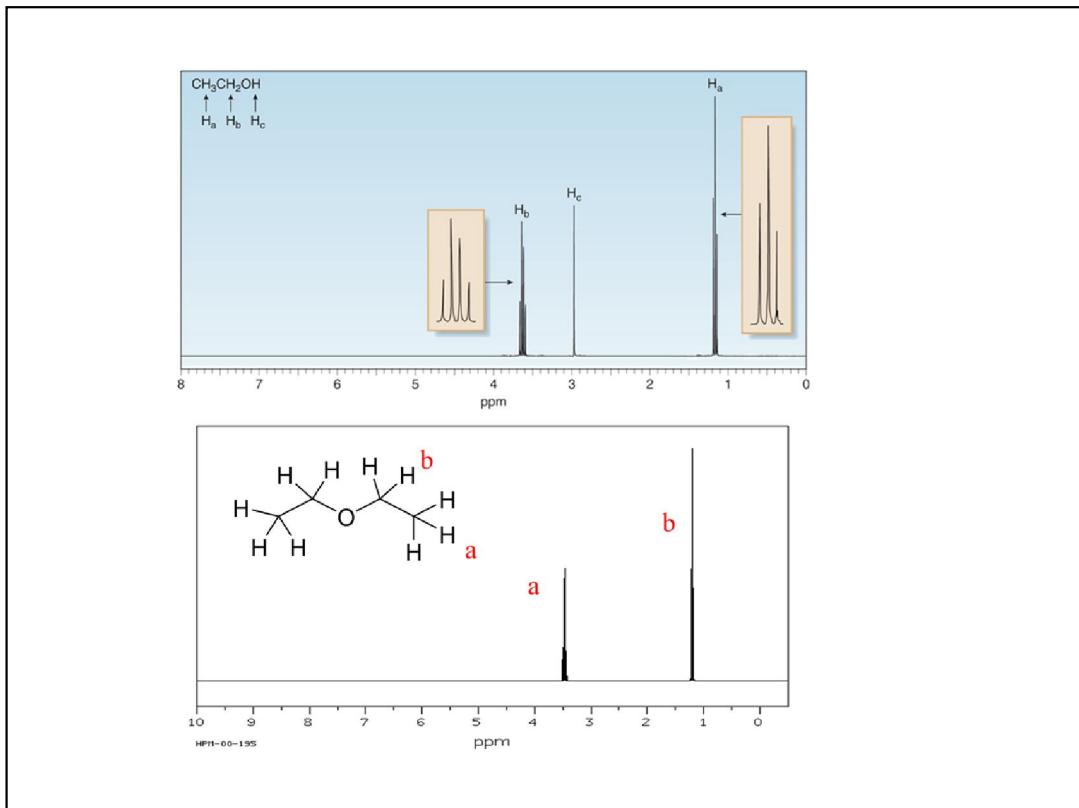
Alcohols

^1H -NMR O-H chemical shift often appears in the range 3.0-4.0, but may be as low as 0.5.

^1H -NMR chemical shifts of hydrogens on the carbon bearing the -OH group are deshielded by the electron-withdrawing inductive effect of the oxygen and appear in the range 3.0-4.0.

Ethers

A distinctive feature in the ^1H -NMR spectra of ethers is the chemical shift, 3.3-4.0, of hydrogens on the carbons bonded to the ether oxygen.



Interpreting NMR Spectra

Aldehydes and ketones

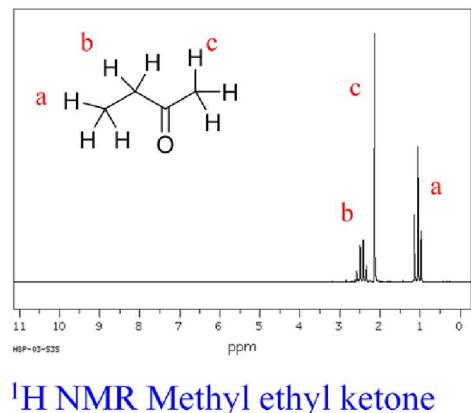
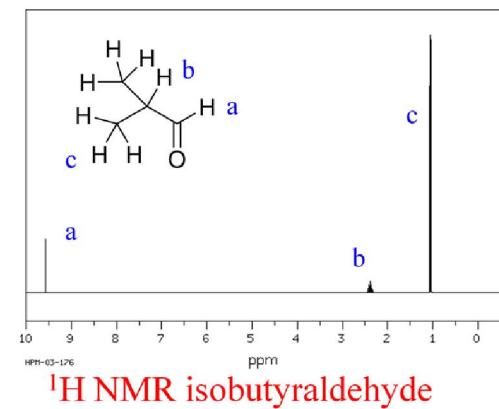
$^1\text{H-NMR}$: aldehyde hydrogens appear at 9.5-10.1.

$^1\text{H-NMR}$: α -hydrogens of aldehydes and ketones appear at 2.2-2.6.

$^{13}\text{C-NMR}$: carbonyl carbons appear at 180-215.

Amines

$^1\text{H-NMR}$: amine hydrogens appear at 0.5-5.0 depending on conditions.

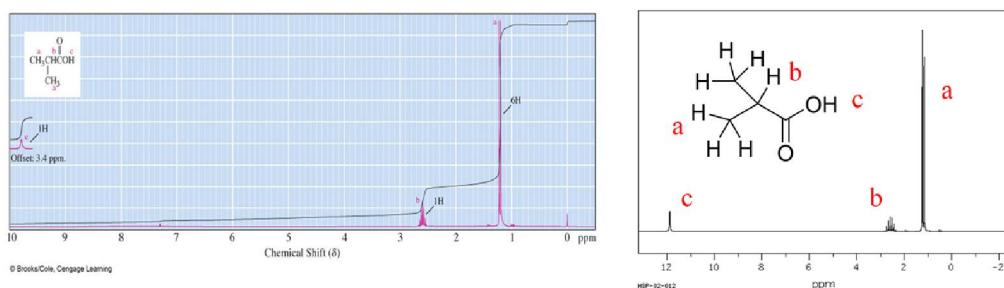


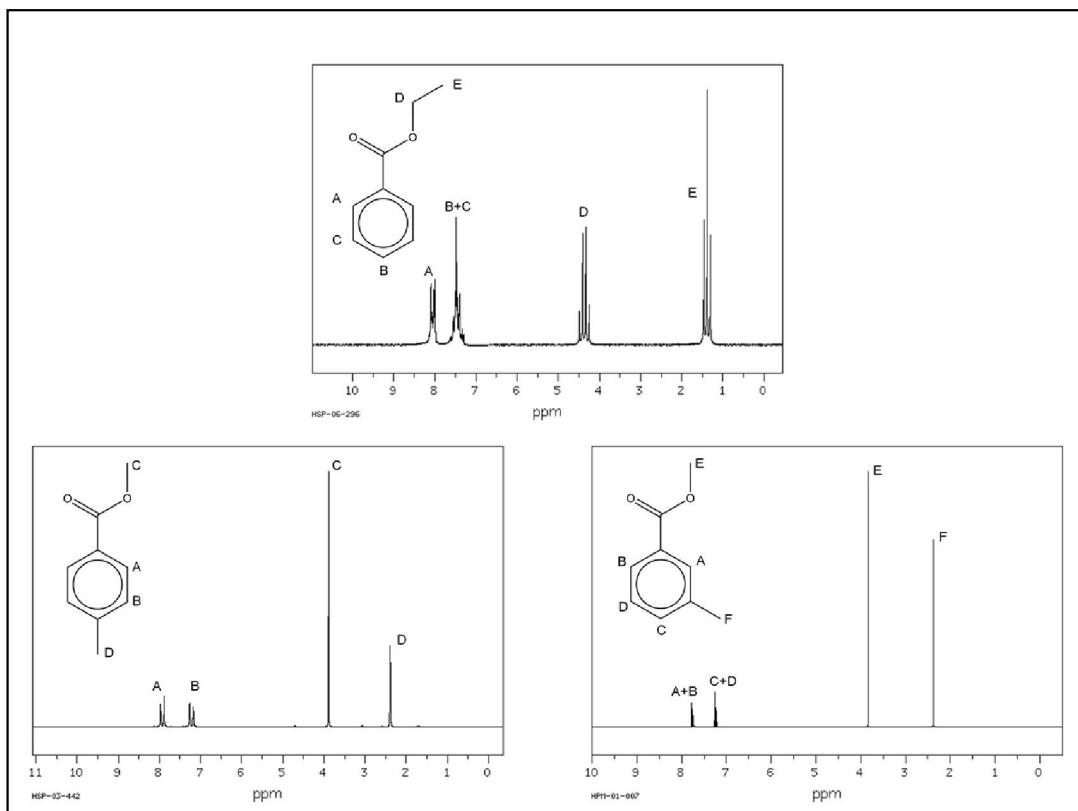
Interpreting NMR Spectra

Carboxylic acids

$^1\text{H-NMR}$: carboxyl hydrogens appear at 10-13 ppm, higher than most other types of hydrogens.

$^{13}\text{C-NMR}$: carboxyl carbons in acids and esters appear at 160-180 ppm.



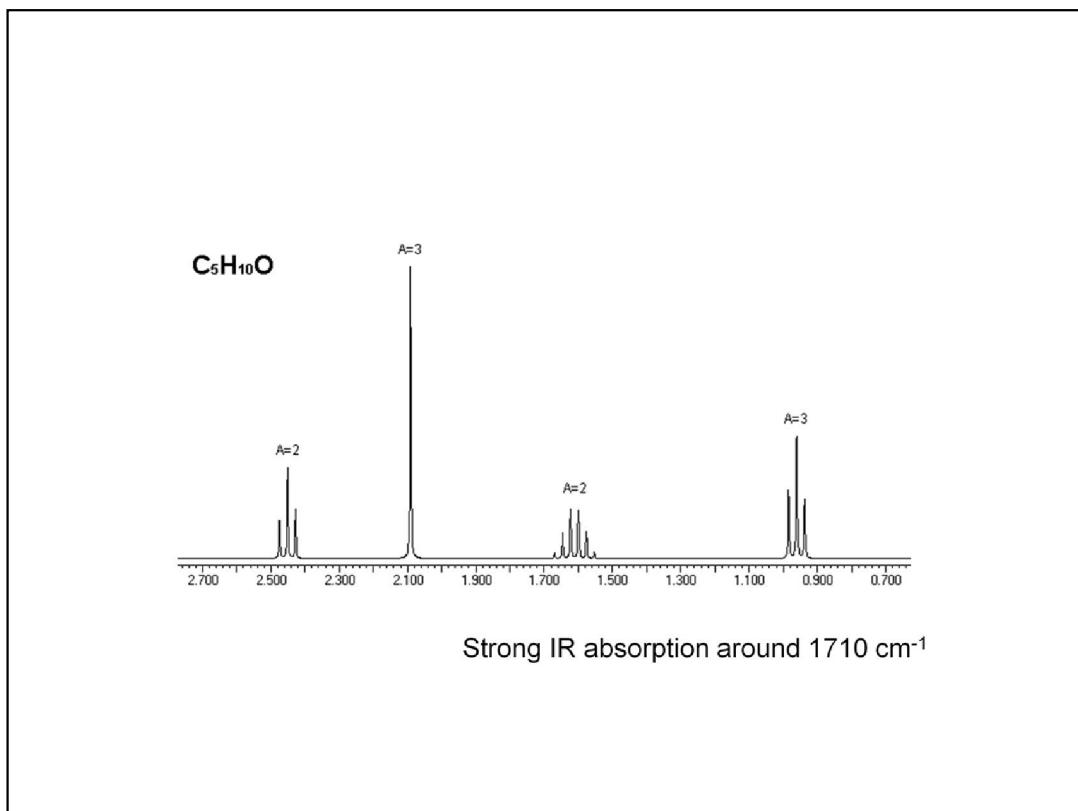


How to determine molecular structure

Number of insaturations:

$$n_{ins} = C + \frac{N}{2} - \frac{H}{2} - \frac{X}{2} + 1 \quad (X=Cl, Br, I)$$

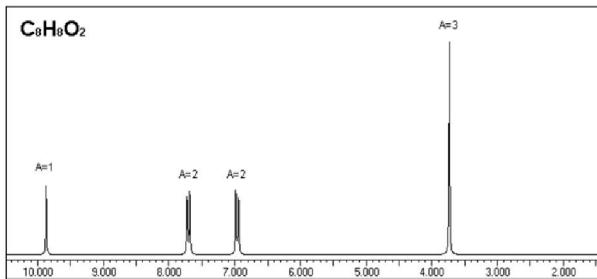
- Multiple bonds
- Cyclic structures



PROBLEMA NMR n. 1

I problemi 1 e 2 riguardano una coppia di isomeri con formula bruta $C_8H_8O_2$.
Lo spettro IR della molecola del problema 1 mostra un picco intenso intorno a 1700 cm^{-1} .
Lo spettro NMR del problema 1 è riportato qui sotto:

spostamento chimico	area	molteplicità
9.87	1	1 (s)
7.70	2	2 (d)
6.96	2	2 (d)
3.73	3	1 (s)

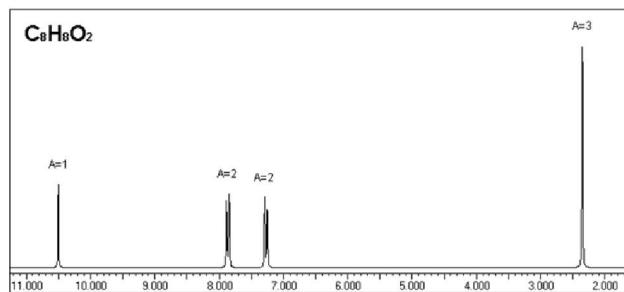


Individuare la molecola che produce questo spettro.

PROBLEMA NMR n. 2

I problemi 1 e 2 riguardano una coppia di isomeri con formula bruta $C_8H_8O_2$.
Lo spettro IR della molecola del problema 2 mostra un picco intenso intorno a 1700 cm^{-1} .
Lo spettro NMR del problema 2 è riportato qui sotto:

spostamento chimico	area	moltiplicità
10.50	1	1 (s)
7.86	2	2 (d)
7.27	2	2 (d)
2.35	3	1 (s)

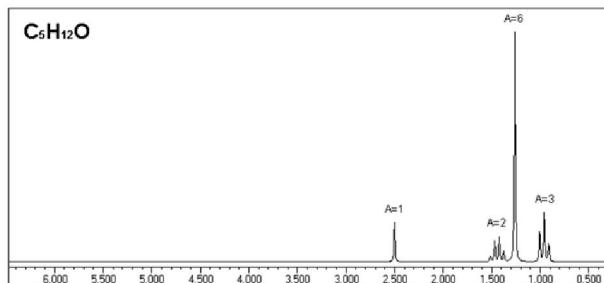


Individuare la molecola che produce questo spettro.

PROBLEMA NMR n. 3

I problemi 3 e 4 riguardano una coppia di isomeri di formula bruta $C_6H_{12}O$.
Lo spettro IR della molecola del problema 3 mostra un picco un po' allargato a 3300 cm^{-1} .
Lo spettro NMR del problema 3 è riportato qui sotto:

spostamento chimico	area	multiplicità
2,50	1	1 (s)
1,44	2	4 (q)
1,26	6	1 (s)
0,96	3	3 (t)

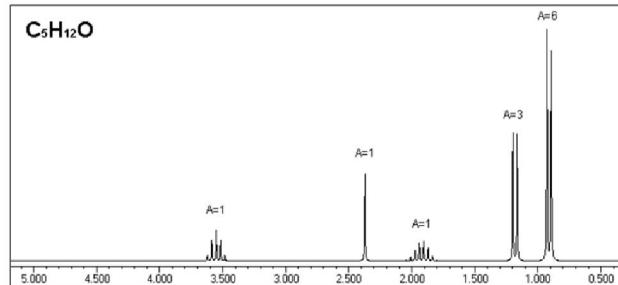


Individuare la molecola che produce questo spettro.

PROBLEMA NMR n. 4

I problemi 3 e 4 riguardano una coppia di isomeri di formula bruta $C_5H_{12}O$.
Lo spettro IR della molecola del problema 4 mostra un picco un po' allargato a 3300 cm^{-1} .
Lo spettro NMR del problema 4 è riportato qui sotto:

spostamento chimico	area	multiplicità
3,55	1	5 (qui)
2,37	1	1 (s)
1,92	1	8 (ott)
1,18	3	2 (d)
0,91	6	2 (d)

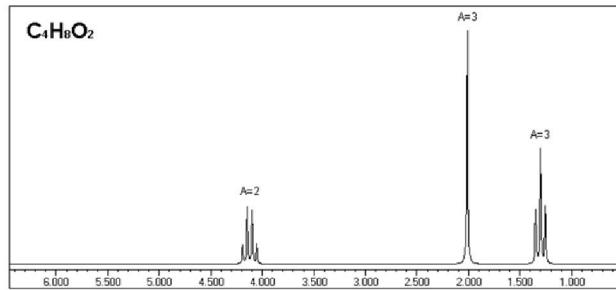


Individuare la molecola che produce questo spettro.

PROBLEMA NMR n. 5

I problemi 5 e 6 riguardano una coppia di isomeri con formula bruta $C_4H_8O_2$.
Lo spettro IR della molecola del problema 5 mostra un picco intenso intorno a 1700 cm^{-1} .
Lo spettro NMR del problema 5 è riportato qui sotto:

spostamento chimico	area	molteplicità
4.12	2	4 (q)
2.01	3	1 (s)
1.30	3	3 (t)

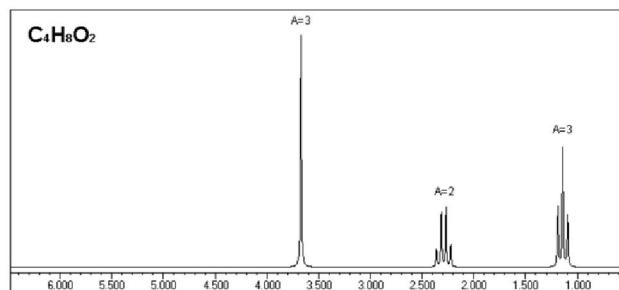


Individuare la molecola che produce questo spettro.

PROBLEMA NMR n. 6

I problemi 5 e 6 riguardano una coppia di isomeri con formula bruta $C_4H_8O_2$.
Lo spettro IR della molecola del problema 6 mostra un picco intenso intorno a 1700 cm^{-1} .
Lo spettro NMR del problema 6 è riportato qui sotto:

spostamento chimico	area	molteplicità
3.67	3	1 (s)
2.29	2	4 (q)
1.14	3	3 (t)

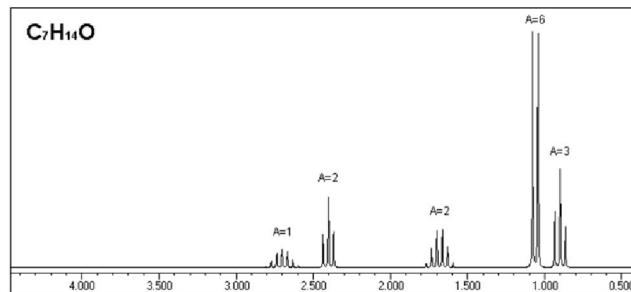


Individuare la molecola che produce questo spettro.

PROBLEMA NMR n. 13

I problemi 11, 12, 13 e 14 riguardano quattro isomeri di formula bruta $C_7H_{14}O$.
Lo spettro IR della molecola del problema 13 mostra un picco intenso intorno a 1700 cm^{-1} .
Lo spettro NMR del problema 13 è riportato qui sotto:
:

spostamento chimico	area	molteplicità
2.70	1	7 (cpt)
2.40	2	3 (t)
1.68	2	6 (ses)
1.08	6	2 (t)
0.90	3	3 (t)

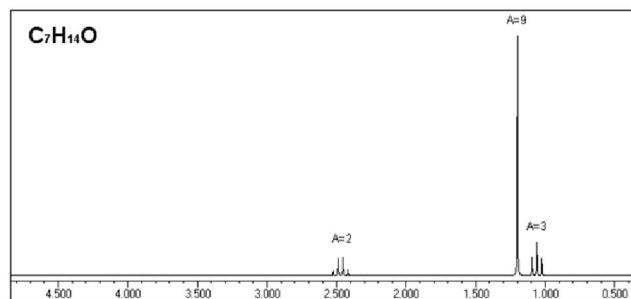


Individuare la molecola che produce questo spettro.

PROBLEMA NMR n. 14

I problemi 11, 12, 13 e 14 riguardano quattro isomeri di formula bruta $C_7H_{14}O$.
Lo spettro IR della molecola del problema 14 mostra un picco intenso intorno a 1700 cm^{-1} .
Lo spettro NMR del problema 14 è riportato qui sotto:

spostamento chimico	area	moltiplicità
2.47	2	4 (q)
1.20	9	1 (s)
1.06	3	3 (t)

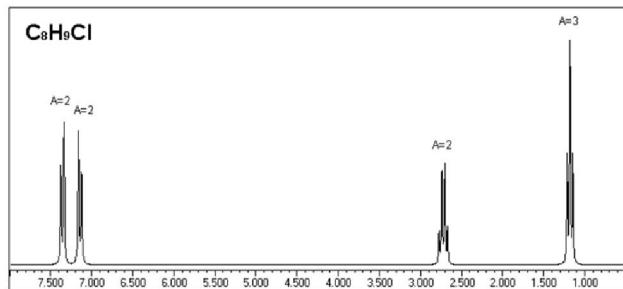


Individuare la molecola che produce questo spettro.

PROBLEMA NMR n. 25

I problemi 25 e 26 riguardano una coppia di isomeri di formula bruta C_8H_9Cl .
Lo spettro NMR del problema 25 è riportato qui sotto:

spostamento chimico	area	moltiplicità
7.32	2	2 (d)
7.14	2	2 (d)
2.72	2	4 (q)
1.18	3	3 (t)

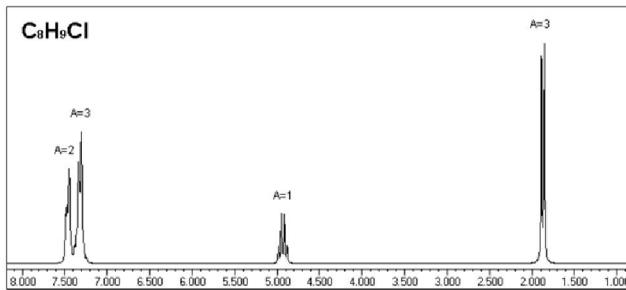


Individuare la molecola che produce questo spettro.

PROBLEMA NMR n. 26

I problemi 25 e 26 riguardano una coppia di isomeri di formula bruta C₈H₉Cl.
Lo spettro NMR del problema 26 è riportato qui sotto:

spostamento chimico	area	multiplicità
7.46	2	?
7.33 - 7.27	3	?
4.93	1	4 (q)
1.87	3	2 (d)

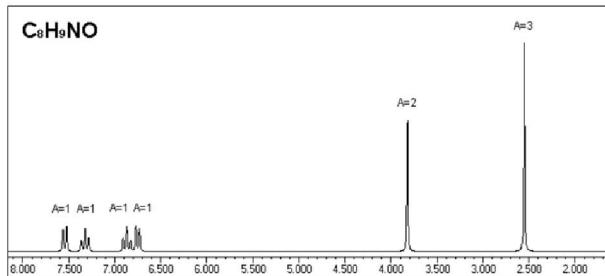


Individuare la molecola che produce questo spettro.

PROBLEMA NMR n. 29

I problemi 29 e 30 riguardano una coppia di isomeri di formula bruta C_8H_9NO .
Lo spettro IR della molecola del problema 29 mostra un picco intenso intorno a 1700 cm^{-1} .
Lo spettro NMR del problema 29 è riportato qui sotto:

spostamento chimico	area	moltiplicità
7.54	1	2 (d)
6.32	1	3 (t)
6.87	1	3 (t)
6.75	1	2 (d)
3.82	2	1 (s)
2.55	3	1 (s)

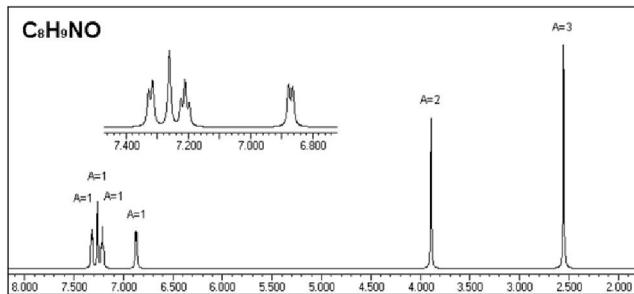


Individuare la molecola che produce questo spettro.

PROBLEMA NMR n. 30

I problemi 29 e 30 riguardano una coppia di isomeri di formula bruta C_8H_9NO .
Lo spettro IR della molecola del problema 30 mostra un picco intenso intorno a 1700 cm^{-1} .
Lo spettro NMR del problema 30 è riportato qui sotto:

spostamento chimico	area	moltiplicità
7.32	1	2 (d)
7.26	1	1 (s)
7.21	1	3 (t)
6.87	1	2 (d)
3.89	2	1 (s)
2.55	3	1 (s)



Individuare la molecola che produce questo spettro.