

NMR Spectroscopy :-

Introduction :-

→ Nuclear magnetic Resonance (NMR)

Spectroscopy is an analytical technique used in quality control and research for determining the content and purity of a sample as well as its molecular structure.

→ It is a technique that exploits the magnetic properties of nuclei.

→ It determines the physical and chemical properties of atoms or the molecules in which they are contained.

→ Different type of NMR Spectroscopy are used,

¹H NMR - used to determine the type and no. of H-atom in a molecule.

¹³C-NMR - used to determine type of carbon atom in the molecule.

Similar for ¹⁵N, ¹⁹F, ³¹P, ²⁹S - NMR.

Theory :-

NMR is a branch of spectroscopy in which radio frequency waves induce transitions between magnetic energy levels of nuclei of a molecule.

The energy of radio frequency radiation can be calculated by.

$$E = hf$$

$h =$ Planck's constant

$$h = 6.626 \times 10^{-34} \text{ erg sec}$$

$f =$ frequency

This energy is very small to vibrate, rotate, but sufficient to affect the nuclear spin of the atoms of a molecule.

Nuclear Spin

→ The nuclei of some atoms have a

property is called "Spin".

→ Each spin-active nucleus has a no. of spins defined by its spin quantum numbers (I).

→ If the no. of neutrons and no. of protons are both even, then nucleus has no spin.

Ex: $^{12}_6\text{C}$, $^{16}_8\text{O}$, $^{32}_{16}\text{S}$ $(I=0)$

→ If the no. of neutron & no. of protons are both odd, then nucleus has spin.

Ex: ^2_1H , $^{13}_6\text{C}$ $(I \neq 0)$

→ If the no. of neutrons & no. of protons, any one is odd then nucleus has half integer spin. $(I \neq 0)$

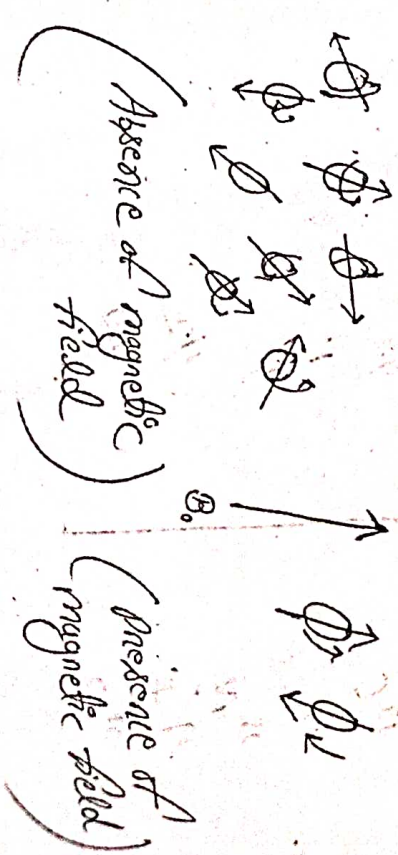
Ex: ^1_1H , $^{19}_9\text{F}$, $^{31}_{15}\text{P}$ $(I = 1/2, 3/2, 5/2)$

Element	Nuclear spin quantum no. (I)
^1_1H	1/2
^2_1H	1
$^{12}_6\text{C}$	0
$^{13}_6\text{C}$	1/2
$^{14}_7\text{N}$	1
$^{15}_7\text{N}$	1/2
$^{19}_9\text{F}$	1/2
$^{31}_{15}\text{P}$	1/2

Element	atomic mass	atomic no.	NMR active
^1_1H	odd	odd	NMR active
$^{13}_6\text{C}$	odd	even	
^2_1H	even	odd	NMR inactive
$^{12}_6\text{C}$	even	even	

When a charged particle such as a proton spins on its axis, it creates a magnetic field. Thus, the nucleus can be considered to be a tiny bar magnet.

Normally, these tiny bar magnets are randomly oriented in space. However, in the presence of a magnetic field (B_0), they are oriented with (or) against this applied field.



In a magnetic field (B_0), there are two energy states for a proton, a lower energy state with the nucleus aligned in the same direction as B_0 and a higher energy state in which the nucleus aligned against B_0 . The frequency needed for resonance and applied magnetic field strength are directly proportional to each other.

$$\gamma \propto B_0$$

Principle :-

→ NMR Spectroscopy is the interaction of magnetic field with spin of nuclei and their absorption of radio frequency.

→ With out the magnetic field spin state of nuclei possess the same energy and energy level transition is not possible.

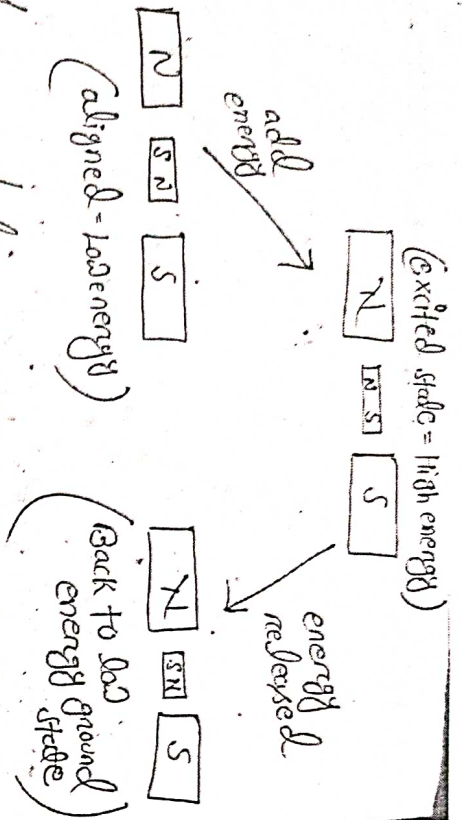
→ When magnetic field applied, separate levels and radio frequency radiation can cause transitions between these energy levels.

→ So the main principle behind NMR is that many nuclei have spin and all nuclei are electrically charged. If an external magnetic field is applied, an energy transition is possible between the ground energy to a higher excited state energy level. The energy transfer takes place at a wavelength that corresponds to radio frequencies and when the spin returns to its ground level energy is emitted at the same frequency.

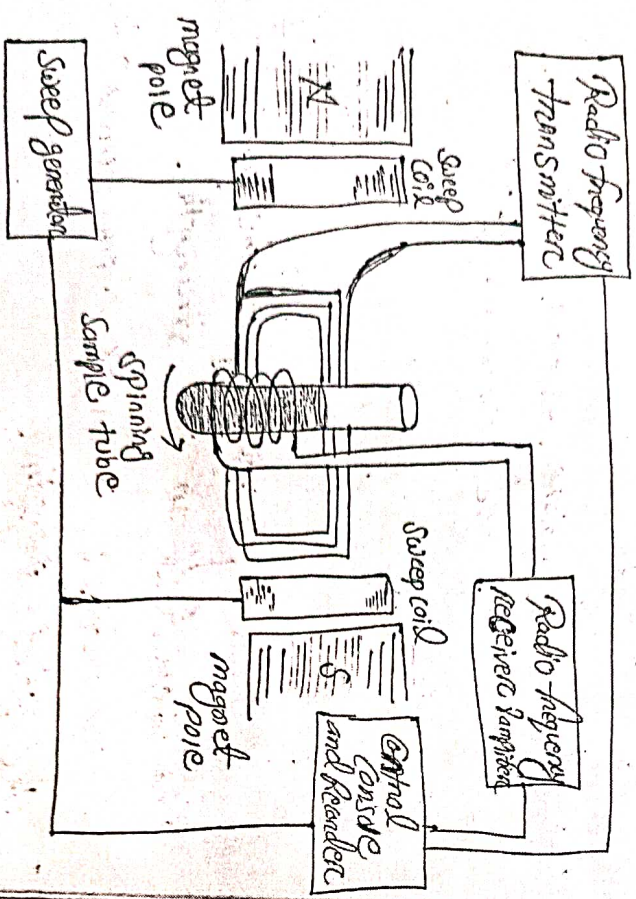
→ The signal that matches this transfer is measured in many ways and processes in order to yield an NMR spectrum for the nucleus concerned.

Resonance Condition

When the frequency of (absorption of energy) radio wave and the frequency of spinning nucleus in magnetic field is equal that phenomenon is called "Resonance".



Instrumentation:-



Sample holder:-

→ 5 mm glass tube is used, which can hold 0.4 ml liquid sample.

→ microtubes are used for low volumes of sample.
 → here we take the sample to which we want to investigate.
 → both liquid and solid type of samples can be used in NMR spectroscopy.
 → In solid-phase, sample like crystals, gel, proteins and all kinds of polymers etc can be used.

→ In liquid phase, different type of liquid for, nucleic acid, carbohydrates etc. can be used.

Magnets:-

Accuracy & quality of the instrument is dependent on its strength.
 Resolution increases with increase in the field strength.

Three types of magnets can be used,

- 1) Conventional magnet (30-60 MHz)
- 2) Permanent magnet (60, 90, 100 MHz)
- 3) Superconducting magnet (470 MHz)

Relationship between B_0 & γ calculated by,

$$\gamma = \left(\frac{f}{2\pi} \right) \theta_0$$

γ = gyromagnetic ratio

Sweep generator and sweep coil :-

→ A set of sweep coil is located parallel to the magnet which allows the magnetic field.

→ The sweep coil control the magnetic field strength.

RF Transmitter :-

It is a pair of coils mounted perpendicular to the path of field and receiver coil.

→ produce the radio frequency wave.

Receiver coil and Amplifier :-

Amplifies the received electronic magnetic radiation by 10^5 times.

(or) Detector :- detects the signal, produced by resonating nuclei.

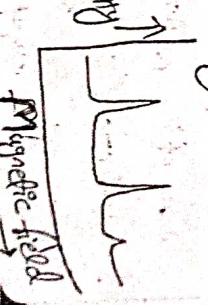
Working :-

When the sample molecule which has odd no. of neutron and proton placed in the the two large magnet. it behave as a tiny magnet and aligned with the magnet field direction. (Low energy = α state).

When radio frequency wave is applied then the sample molecule absorb that particular frequency of radiation and flip against the magnetic field direction means it go higher excited energy level (β -spin state) and after relaxation it come back to ground state by emitting radiation and that is detected by the detector and will get a NMR signal spectrum in computer.

Spectrum :-

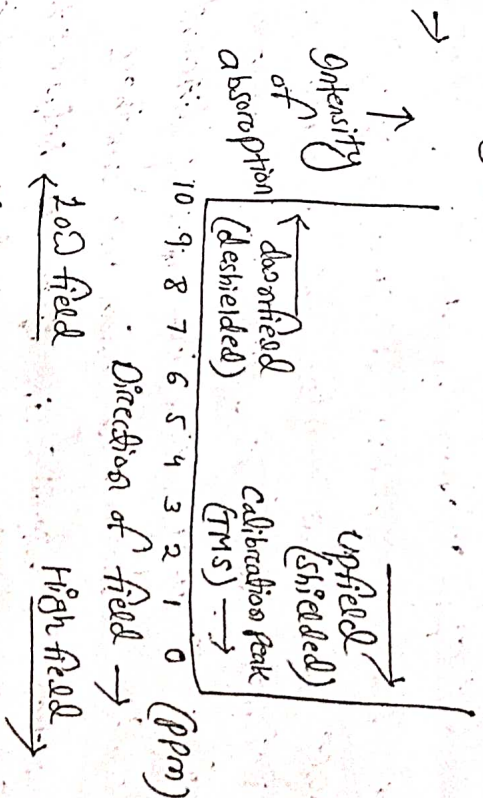
NMR spectrum is plot of intensity of NMR signal versus magnetic field in reference to TMS. (tetra methyl silanes)



Chemical shift :-

- It shows the position of signals.
- The utility of NMR is that all protons do not show resonance at same frequency because, it is surrounded by particular no. of valence electrons which vary from atom to atom. So, they exist in slightly different electronic environment from one another.
- Position of signals in spectrum help us to know nature of protons. that is, aliphatic, aromatic, allylic, adjacent to electron releasing or withdrawing group. Thus they absorb at different field strength.
- The relative energy of resonance of a particular nucleus resulting from its local environment is called chemical shift.
- NMR spectra show applied field strength increasing from left to right.
- Left part is down field, right part is up field.

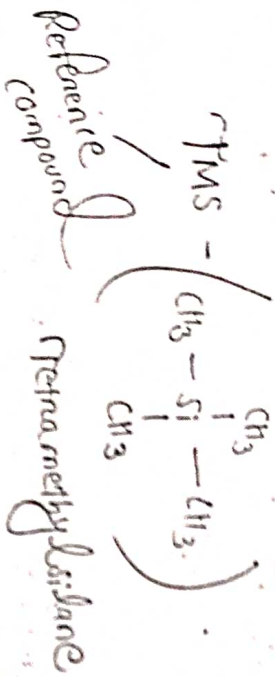
- Nuclei that absorb on up field side are strongly shielded.



Measuring chemical shift :-

- Numeric value of chemical shift: difference between strength of magnetic field at which the observed nucleus resonates and field strength for resonance of a reference.
- For measuring chemical shifts of various protons in a molecule, the signal of TMS is taken as reference.
- The NMR signal for particular protons will appear at different field strength compared to signal from TMS.

→ The difference in the absorption position of the proton with respect to TMS signal is called as chemical shift (δ -value).



→ TMS is most commonly used as reference in NMR due to the following reasons:

- 1) It is chemically inert
 - 2) It is highly shielded
 - 3) It gives a small peak even small quantity.
 - 4) It is highly volatile
 - 5) It is less electronegative than carbon
 - 6) It can be easily removed to get back sample.
- The "chemical shift" in the following way:

$$\text{Chemical shift} = \frac{\text{Shift in Hz}}{\text{Spectrometer frequency in MHz}} = \text{PPM (parts per million)}$$

T-scale:

→ The alternative system which is generally used for defining the position of resonance relative to the reference is assigned as τ scale.

$$\tau = 10 - \delta$$

→ A small numerically value of δ indicates a small downfield shift while large value indicates a large downfield shift.

→ A small value of τ represent a low field absorption and a high value indicates a high field absorption.

Factors affecting Chemical shift:

1) Electronegativity: (electronegative group)

Electronegative groups attached to the C-H system decrease the electron density around the protons, and there is less shielding (deshielding) and chemical shift increases.

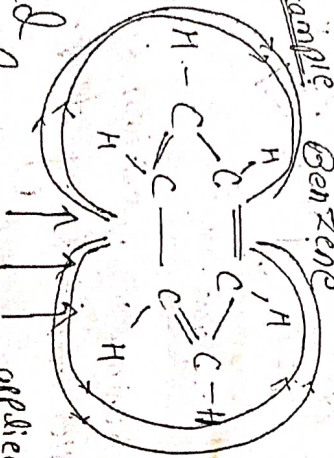
Ex: δ -value



2) Anisotropy field :-

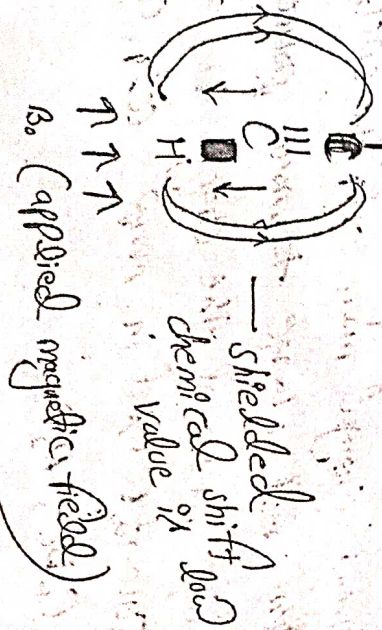
→ magnetic anisotropy arises that there is a nonuniform magnetic field.
 → electrons in π systems (ex: aromatic, alkenes, alkynes, carbonyls) interact with the applied field which induces a magnetic field that causes the anisotropy.
 → It causes both shielding and deshielding of protons.

Example Benzene



deshielded
 chemical shift is high
 B. (magnetic field)

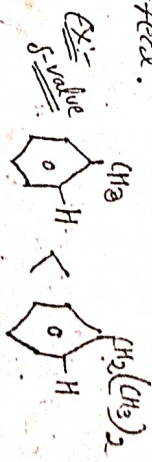
Ex:-



shielded
 chemical shift is low

3) Vander Waals deshielding

→ The electron cloud of a bulky group will tend to repel the electron cloud surrounding the proton.
 → Such a proton will be deshielded and will resonate at slightly higher value of δ than expected in the absence of this effect.



Effect of Temperature :-

Resonance position of most signals is little affected by temp.

Effect of Solvent :-

Chemical shift change when the solvent changed from $CDCl_3$ to $CDCl_3$ is 0.1 ppm. But change to more polar solvents like methanol, the change is 0.3 ppm. Solvents used in NMR: $CDCl_3$, CS_2 , $CDCl_3$, C_6D_6 , D_2O .

of Hydrogen bonding :-

→ Protons that are involved in hydrogen bonding are typically change the chemical shift value.

→ The more hydrogen bonding the more proton is deshielded and chemical shift value is higher.

Shielding and deshielding :-

→ Rotation of electrons to nears by nuclei generate field that can either oppose or strong the field on proton.

→ If magnetic field is oppose applied magnetic field on proton, that proton said shielded proton and if field is strong the applied field then, proton feels high magnetic field strength and such proton called as deshielded proton.

→ So, shielded proton shifts absorption signal to right side (up field) and deshielded proton shifts absorption signal to left side (down field) of spectrum.

→ So, electric environment surrounding protons tells us where proton shows absorption in spectrum.

→ The electrons around the proton create a magnetic field that opposes the applied field. since this reduces the field experienced at the nucleus, the electrons are said to shield the proton.

→ When the secondary fields produced by the circulating electrons oppose the applied field at a particular nucleus in the molecule, it means that effective field experienced by the nucleus is less than the applied field. This is known as positive shielding and the resonance position moves up field in NMR spectrum.

→ If the secondary field produced by the circulating electrons reinforces the applied field, the position of resonance moves downfield. This is known as negative shielding.

→ Shielding-upfield: higher electron density requires a stronger field for resonance.
→ deshielded - downfield - lower electron density requires a weaker field for resonance.

Relaxation Process:-

The mechanism by which the nucleus in the higher energy state can lose energy to its environment and then return to its lower energy state is called the nuclear relaxation process.

There are two types of relaxation processes, 1) Spin-Spin relaxation

2) Spin-Lattice relaxation

1) Spin-Spin relaxation:-

When two protons/spinning nuclei come close to one another the nucleus in high energy state transfers its excess of energy to the neighbouring lower energy state nuclei and come to ~~ground~~ ground state.

By emitting radiation this mutual exchange of spin give rise to Spin-Spin relaxation. It does not alter the population distribution but its limits the time spent by the nuclei in higher energy state.

2) Spin-Lattice Relaxation:-

The nucleus in the higher energy state transfers its energy to the other nuclei in the surrounding molecular frame work, that is, lattice. Thus bringing that nucleus in low energy state. The time taken for this transition is known as Spin-Lattice relaxation time.
→ This will represent the lifetime of the nucleus in the higher energy state.
→ For solid sample the relaxation time 10^{-4} to 10^{-8} sec.
→ For liquid sample the relaxation time 10^{-4} to 10 sec.
→ It can alter the population distribution in ground state and will get a continuous path.

Spin-Spin Splitting (Spin-Spin Coupling)

The interaction between the spins of neighbouring nuclei in a molecule may cause the splitting of NMR spectrum. The splitting pattern is related to the no. of equivalent H-atom at the near by nuclei.

Ex: Ethyl acetate



① → Singlet - 3 equivalent protons. not coupled to any neighbouring proton.

② → Quartet - 2 equivalent protons.

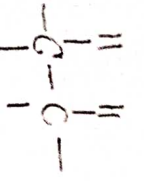
Split (1:3:3:1) because coupled to the 3-H of CH₃.

③ → Triplet - 3 equivalent protons

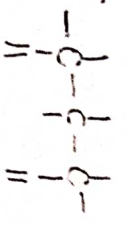
Split (1:2:1) because coupled to the 2-H of CH₂.

Rules for Spin-spin coupling:

- 1) Chemically equivalent protons do not show spin-spin coupling and only non equivalent protons ~~will~~ couple.
- 2) Protons on adjacent carbony normally will couple.
- 3) Protons separated by four or more bonds will not couple.



(splitting observed)

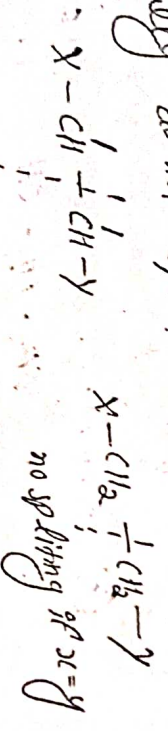


(splitting not observed)

→ Measurement of splitting effect is based on the distance between the peaks in a given multiplet.

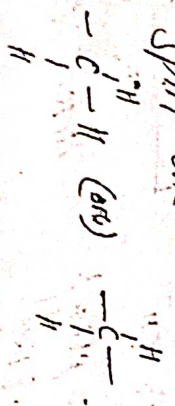
→ The 1:3:3:1 peaks are due to spin-spin splitting and are predicted by (n+1) rule.

→ Protons that are equivalent by symmetry usually do not split one another.

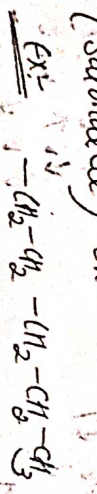


split if x ≠ y

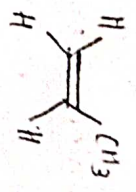
→ protons in the same group usually do not split one another.



→ (n+1) rule applies to protons in aliphatic (saturated) chains are on saturated rings.



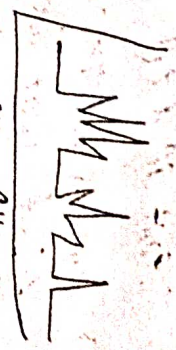
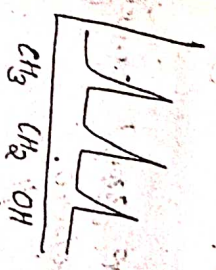
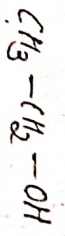
→ But does not apply to protons on double bonds or on benzene rings.



Spin of one proton is coupled with spin of another proton which nearby it. For spin-spin coupling we need two set of protons.

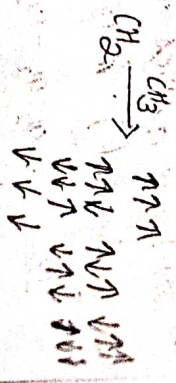
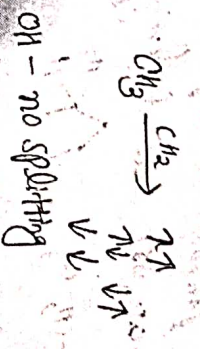
Due to spin-spin coupling, splitting of signal will occur so it is called spin-spin splitting.

Ex: Ethanol



before coupling / splitting

After coupling / splitting



Spin-spin coupling will divided the spin peak splitting.
 → peak intensity represented by Pascal triangle

- Two singlet 1
- Doublet 1:1
- Triplet 1:2:1
- quartet 1:3:3:1
- Pentate 1:4:6:4:1 and so on.

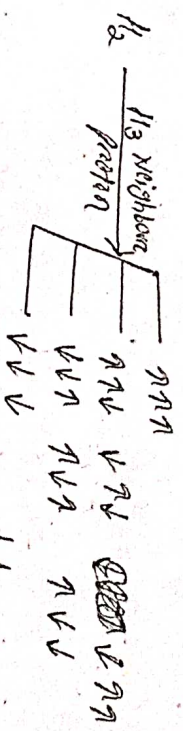
Spin-decoupling :- (double resonance)

It is a technique which involved irradiation of 1 proton or set of proton, this irradiation is done by intense radio frequency energy. Eliminates spin-spin

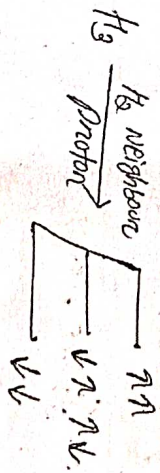
This energy proton. Coupling among

Example Spin-spin coupling in ethanol
 $\text{CH}_3\text{-CH}_2\text{-OH}$
 (a) (b) (c)
 a' - proton ~~are~~ give only singlet
 because there is no carbon attached
 this proton.

So there is no spin-spin coupling.
 H $\xrightarrow{\text{No neighbour proton}}$ L singlet peak

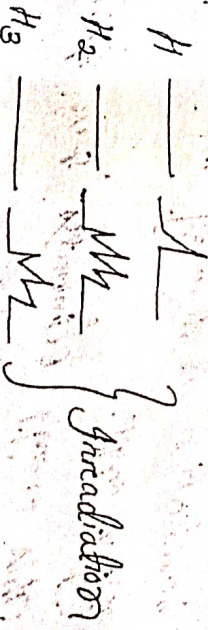


quartet peak



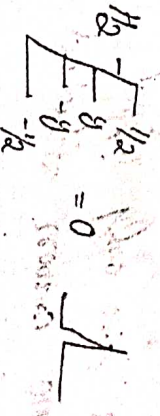
triplet peak

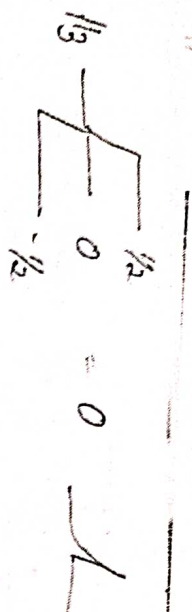
when double resonance occur it will decoupling in this way.



And this protons will be irradiated them self by using intense radio frequency

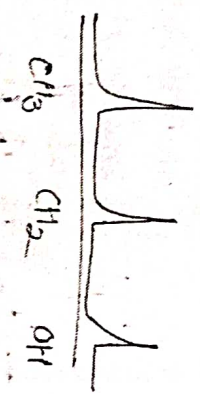
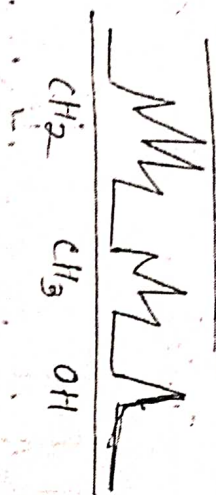
H - No effect because no neighbour proton





before decoupling

after decoupling



→ This radio frequency is used, so instead of double resonance at double irradiation.

→ This technique is a powerful tool for ~~more~~ simplifying the spectrum.

→ Spin-spin decoupling help to identify also the relative position of proton in a molecule and for locating complex absorption molecule.

Spin flipping:

→ This is a modified spin decoupling technique.

→ It involves the irradiation of a line of a multiplet with a weak intense radio frequency radiation instead of irradiating the whole multiplet with powerful / high intense radio frequency radiation is called spin flipping.

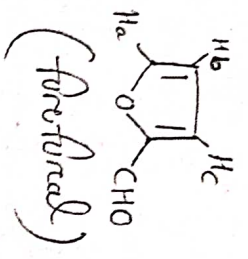
→ Due to greater strength of irradiation and in decoupling, that are not suitable for compounds having the small chemical shift value difference, for that spin flipping is used.

→ It is used for that compound whose chemical shift difference between ~~the~~ protons is very less / almost nearly equal.

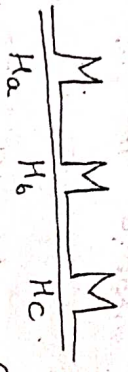
→ It is used to remove coupling phenomenon ~~between~~ in protons which having the lower chemical shift value.

Difference.

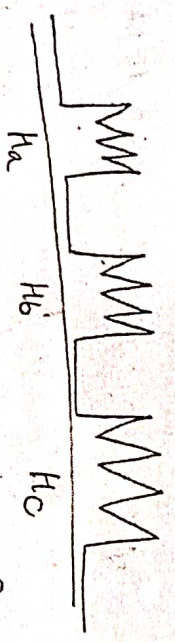
Example



H_a, H_b, H_c are 3 non equivalent protons.
 In general, H_a coupled with H_b and H_c give doublet and similar for H_b and H_c .
 H_b coupled to H_a and H_c coupled to H_b to give doublet.



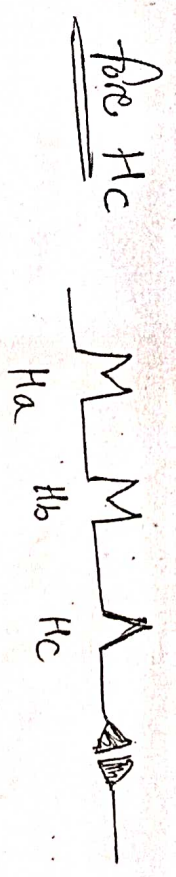
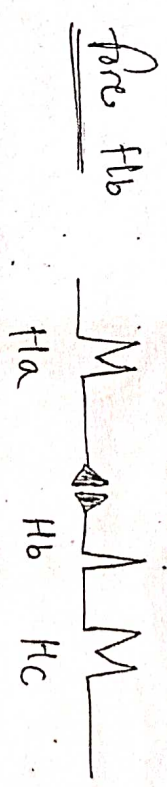
But when the chemical shift value difference is larger between H_a, H_b, H_c then H_a coupled with both H_b and H_c to give quartet and similar for H_b and H_c .



In that case to get a simplified spectra we can not use ⁿ spin decoupling.

here we use spin flipping technique.

In spin flipping, which proton signal we want to get simplified on that a low intense radio frequency radiation is irradiated to make it singlet and also remaining signals are simplified.



In spin flipping we use low intense radio frequency radiation.

Shift reagent :-

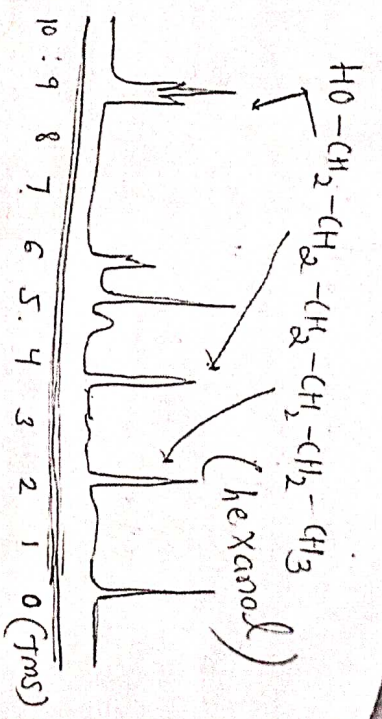
NMR is one of the most important analytical method of structure elucidation organic, bioorganic and organometallic compound.

The organic molecule mainly contain Carbon and hydrogen, thus most of the structural information is carried out by Carbon and proton NMR data.

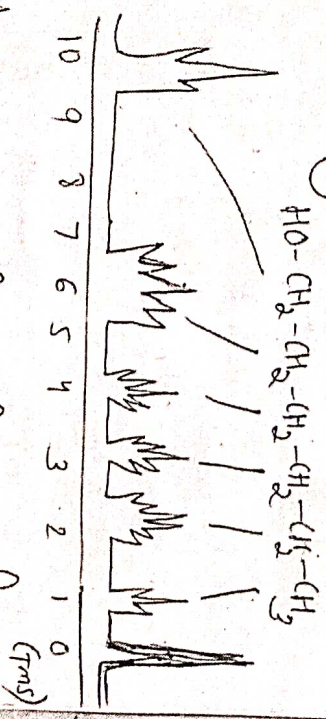
The ability of NMR to distinguished between two compound and part of compound is increased by using shift reagent.

The most efficient shift reagent are the complex of lanthanides lanthanide shift reagents used for stereochemical determination.

- Commonly used lanthanide shift reagents,
- Eu (Fod)₃ [Europium tris heptafluorodimethylacetate]
 - Eu (Dpm)₃ [Europium tris dipivaloylmethane]



After adding lanthanide shift reagent,



→ In NMR, shift reagent is used to simplify the spectra.

→ They should make complex with the compound under study. Therefore organic compounds having following functional groups can be studied using shift reagents; amine, alcohol, ketone, aldehydes, ethers, esters, nitriles, etc.

→ Shift reagents provide a useful technique for spreading out NMR absorption patterns which normally overlap, with out increasing the strength of applied magnetic field.

→ when shift reagent is added to the compound for which spectrum is being determined, profound shifts in the resonance positions of the various group of protons are observed.

→ The direction of the shift (upfield or downfield) depends primarily on which metal is used.

→ Complex of Europium, erbium, thulium, and ytterbium shift resonance to lower field (large δ value), while complex of cerium, neodymium, praseodymium, samarium, terbium, holmium generally shift resonance to higher field.

→ when shift reagent to core analyte compound molecule sample, it co-ordinate with those sample molecule and shift the e^- density and form a co-ordinate compound and this will shift the electron density and make the signal separable, clear and simplify.

Solid state magic angle NMR:

A problem with the examination of Solids is that the nuclei can be considered to be frozen in space and cannot freely line up in the magnetic field.

The NMR signals generated are dependent among other things, on the orientations of the nuclei. The randomly oriented nuclei therefore give broad band spectra which are not very useful analytically.

It can be shown that when one rotates a solid sample such that its axis of rotation is 54.7° (the magic angle) to the direction of the applied magnetic field, the broadening caused by random nuclear orientations tends to be averaged out, resulting in narrower spectra. This, of course, is more useful analytically because it allows better resolution and therefore better measurement of chemical shift and spin-spin splitting. In turn, this is very informative of the functional

groups and their positions relative to each other in the sample molecule.

Special probes have been developed for magic-angle NMR which automatically position the sample, making the method a more practical procedure with ordinary instruments.

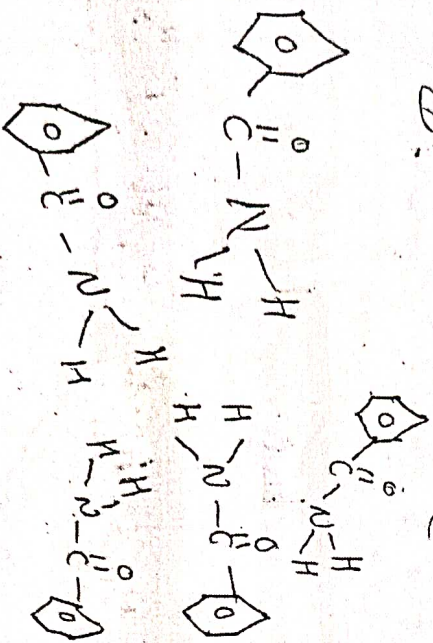
The method has proved very useful for studying solid samples.

Solid

Solid state NMR is less favourable than liquid state NMR, because of,

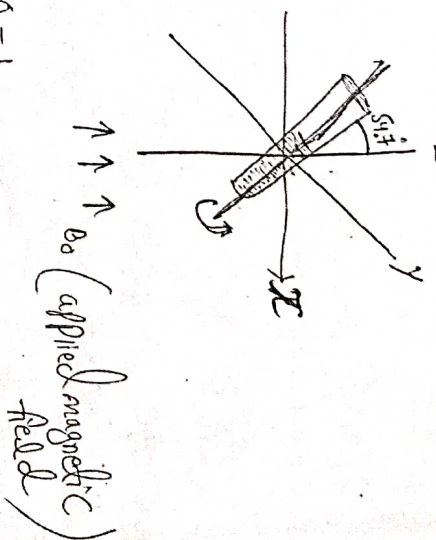
- ① Anisotropy effect
- ② longer relaxation period

Ex: Benzamide ($C_6H_5CONH_2$)



Anisotropy orientation $3 \cos^2 \theta - 1$

Magic angle (54.7°)

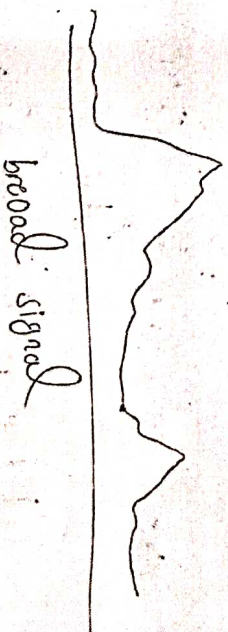


$$= 3 \cos^2 \theta - 1$$

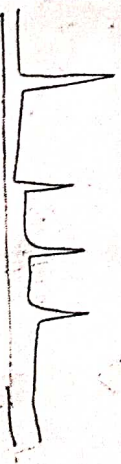
$$= 3 \cos^2 54.7^\circ - 1$$

$$= 0 \quad (\text{Anisotropy effect will remove})$$

with out magic angle NMR



after apply magic angle NMR



FT-NMR :- (Fourier Transform NMR)

It is the mathematical operation in which the complex wave form can be broken-down into simple mathematical operations.

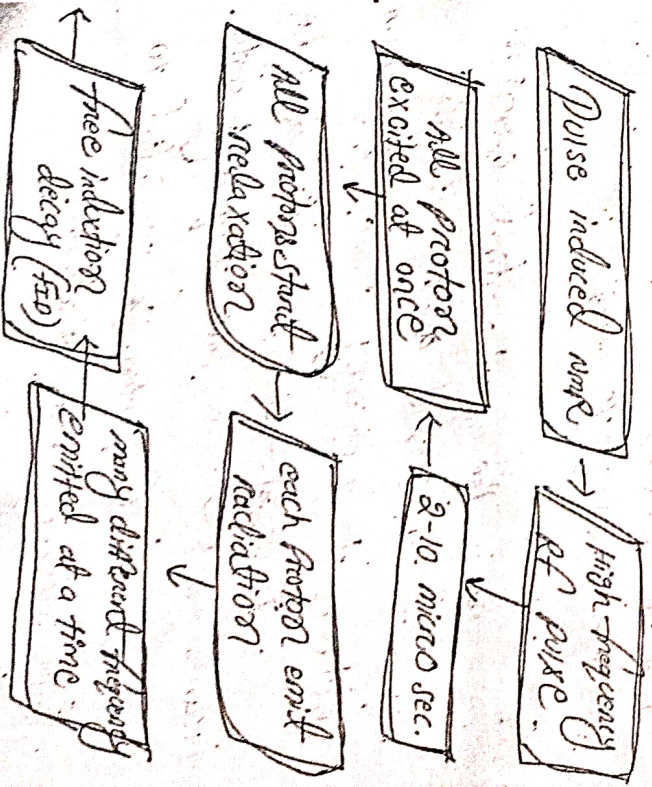
It is the mathematical operation required to convert a time domain spectrum to frequency domain spectrum.

~~Following~~ This data must be transformed into the frequency data.

A Computer is essential to solve these complex equations.

FT NMR use pulse NMR, the sample is irradiated periodically with brief, highly intense pulses of radio-frequency radiation producing which the free induction decay signal - a characteristic radio-frequency emission signal stimulated by the irradiation is recorded as a function of time.

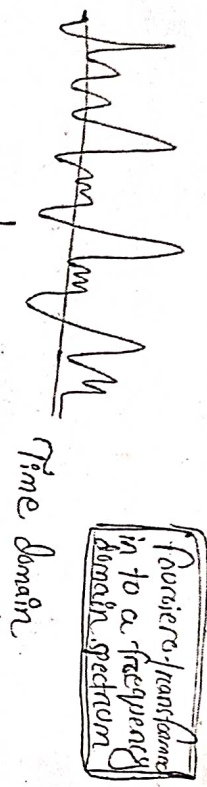
The frequency-domain spectrum can be obtained by a Fourier transform employing a digital computer.



NO Signal
the Vector
Landscape

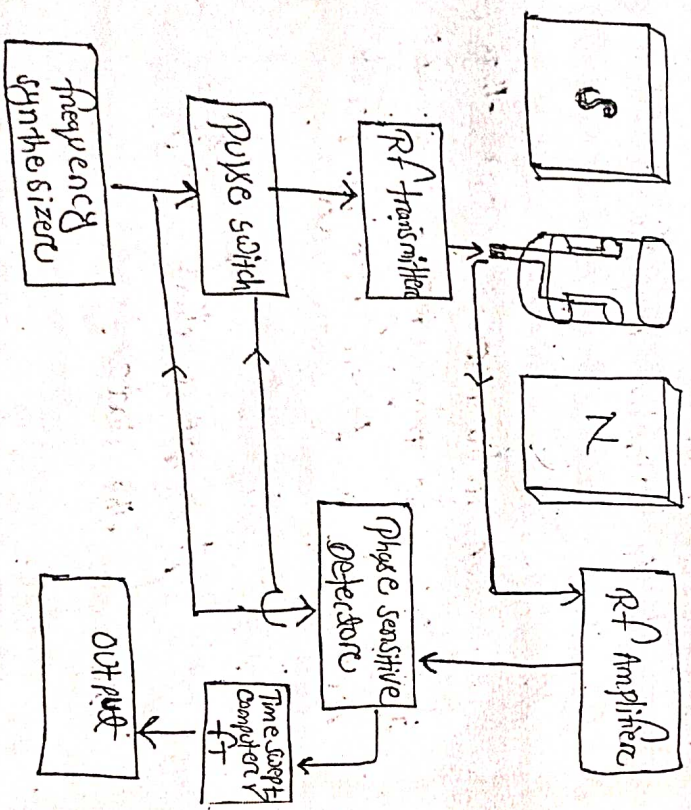
1D signals (containing their vector sum of the responses from all spins)

A time domain spectrum is obtained



Fourier transform in to a frequency domain spectrum

Instrumentation :-



radio transmitter coil :-

A radio transmitter coil that produces a short powerful pulse of radio waves

powerful magnet :-

A powerful magnet that produces strong magnetic fields.

those of continuous wave instruments.

Sample holder :-

The sample is placed in a glass tube that spins so the test material is subject to uniform magnetic field.

Radio receiver coil :-

A radio receiver coil that detects radio frequencies emitted as nuclei relax to a lower energy level.

Computer :-

A computer that analyses and records the data.

Power of RF pulse:

- The intensity of the signal detected in pulsed NMR is a function of the power of RF pulse used for excitation.
 - Suitable RF power and pulse width cause magnetization to rotate by 90° pulse.
 - Relaxation process occurs
 - The magnitude of the magnetization decreases with time.
 - The resulting signal is known as free induction decay (FID)
- ## Pulse duration and recycling time:
- All precessional frequencies within the effective band width of the pulse are excited.
 - The extent is inversely proportional to the duration of pulse in the time domain.
 - The broader the pulse spectral region, the shorter is the pulse.

Detection

- Detects the decay of magnetization with respect to time.
- The FID corresponding to absorption of a ~~single~~ single frequency spectrum is a simple exponentially decaying sine wave.
- The FID, modulated by all the frequencies consists of a set of interfering wave forms along with noise.
- FID related with time is called time domain spectrum.

Advantages:-

- 1) Dramatic increase in the sensitivity of NMR measurement.
- 2) has wide application for ^{13}C , ^{31}P , ^{19}F NMR.
- 3) can be obtained with less than 5mg of the compound.
- 4) The signals stand out clearly with almost no electronic background noise.
- 5) MRI is most prominent FT-NMR

Applications.

Applications of NMR:

1) Chemistry

→ By studying the peaks of nuclear magnetic resonance spectra, chemists can determine the structure of many compounds.

→ It can be very selective tech. distinguish among many atoms with in a molecule but which differ only in terms of their local chemical environment.

→ Identification of structural defects in polymers.

→ Detection of hydrogen bonding.

→ Detection of anomalies.

→ Detection of electronegative atoms or groups.

→ Proof.

2) Purity determination

Structural NMR is primarily used for structural determination and also be used for purity determination.

This technique requires the use of an internal standard of a known purity.

3) Medicine

Useful for identifying drug leads and determining the conformations of the compound bound to enzymes, and other proteins.

NMR scanners use strong magnetic field, electric field gradients, and radio waves to generate image of the organs in the body.

4) Industry

It is used to measure rock porosity, estimate permeability from pore size distribution, and identify pore fluids (oil, water and gas).

To study molecular structure and interactions and for determining 3D structure of proteins and other macromolecules.

Process Control

AMP has entered the area of real-time process control and process optimization.

different type of NMR, analysis are utilized to provide real time analysis of feeds and products in order to control and optimize unit operation.

→ used in food science.

→ used in pharmaceutical science and drug.

→ clinical and scientific research

→ Polymer and rubber

→ Organo- ^{13}C compounds are investigated by solid state ^{31}P -NMR.

Ex: $\text{CaSO}_4 \cdot \text{H}_2\text{O}$.

^{13}C NMR Spectroscopy:

Introduction

In all carbon atoms about 11%.

of all carbon atoms are the ^{13}C isotopes the rest is ^{12}C . obtaining ^{13}C spectra

is more complex than for proton NMR. This is primarily because of the low isotopic abundance of ^{13}C in the nature. ^{13}C NMR relies on the magnetic properties of the ^{13}C nuclei.

Carbon- 13 nuclei fall in to a class known as "spin $\frac{1}{2}$ " nuclei for reasons. One effect of this is that a ^{13}C nucleus can behave as a little magnet. ^{12}C nuclei don't have this property.

Principle:

→ The theory behind NMR comes from the spin of a nucleus and it generates a magnetic field. With out an external applied magnetic field, the nuclear spins are random in directions. But when an external magnetic field (B_0) is present the nuclei align themselves either with (or) against the field of the external magnet.

→ If an external magnetic field is applied an energy transfer (ΔE) is possible $\frac{1}{2}$

ground state to excited state. when the spin returns to its ground state level. The absorbed radio frequency energy is emitted at the same frequency level. The emitted radio frequency signal will give the NMR spectrum of the concerned nucleus.

→ The emitted radio frequency is directly proportional to the strength of the applied field.

$$\nu = \frac{h\nu}{2\pi}$$

Characteristic features of ^{13}C NMR:-

- The chemical shift of the ^{13}C NMR is wider in comparison to ^1H NMR.
- ^{13}C - ^{13}C coupling is negligible because of 100% natural abundance of ^{13}C in the compound.
- Protein coupled spectra the signal for each carbon or a group of magnetically equivalent carbon is split by protons bonded directly to that carbon and the $(n+1)$ rule is followed.

- ^{13}C nucleus is about one-fourth the frequency required to observe proton resonance.
- The chemical shift is greater for ^{13}C along chain for proton due to direct attachment of the electronegative atom to ^{13}C .

$$\left[\begin{array}{l} \text{value} \\ \delta \text{ for } ^{13}\text{C NMR} - (0-220 \text{ ppm}) \\ \text{relative to TMS} \end{array} \right]$$

Nuclear Overhauser Effect (NOE)

- Many occasions arise when even coupling constants (the distance between the centres of the two adjacent peaks in a multiplet is usually constant and is called as coupling constant) do not help us in our quest for stereochemical information.
- 'NOE' is a method that allows us to tell which groups are close to **one** another in space even when there are no coupling constants to help out.
- The idea is that as certain selected protons are irradiated by another Radio

low frequency.

→ Under these conditions of the experiment, this causes protons that were in the proximity of the irradiated protons would appear as a slightly more intense peak in the NMR spectrum. This effect is known as the "nuclear Overhauser effect."

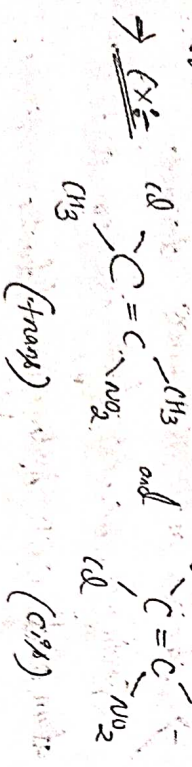
→ This phenomenon discovered by "Albert Overhauser in 1953".

→ Not process can be summarized as a cross relaxation from one spin state to another spin state.

→ It play an important role in modern NMR spectroscopy.

→ Here we determine the position of a proton (which one not neighbouring) in a molecule by double irradiating one of the proton and study its impact on others.

Proton in space.



Sample Preparation in NMR :-

1) Use the proper amount of material

2) Use proper solvent and amount of solvent. Generally deuterated solvent are used.

3) Consider preparing your sample in a secondary vial.

4) Use clean, unscratched NMR tubes and clean caps. High quality NMR tubes are available.

5) Use an internal standard such as TMS. Internal standards can be added directly to the sample if desired.

6) Label your sample.

7) Air sensitive sample → some samples must be degassed to remove oxygen. For degassing air-sensitive samples can be directly attached to a vacuum line.

OFF Resonance :-

→ In an off resonance decoupled ^{13}C spectrum, the coupling between each carbon atom and each hydrogen attached directly to

~~the~~ that carbon.

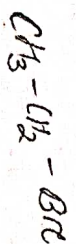
→ The (n+1) rule can be used to determine whether a given carbon atom has three, two, one or no hydrogens attached.

→ when off resonance decoupling is used, the coupling constant is reduced.

Ex: off resonance decoupled spectrum of 1-propanol, in which the methyl carbon atom is split into a quartet and each of the methylene carbons appears as a triplet. The observed multiplet pattern are consistent with the (n+1) rule.

→ off resonance decoupling can simplify the spectrum.

Ex: ethyl bromide



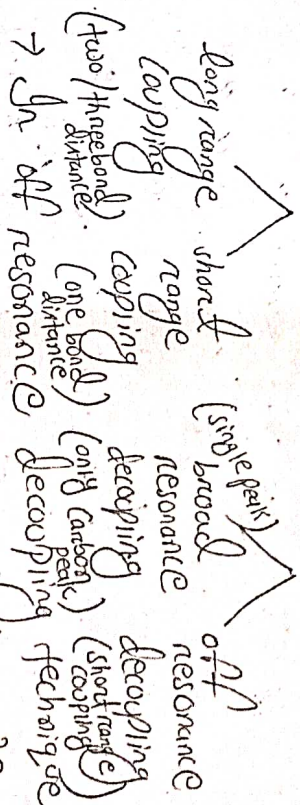
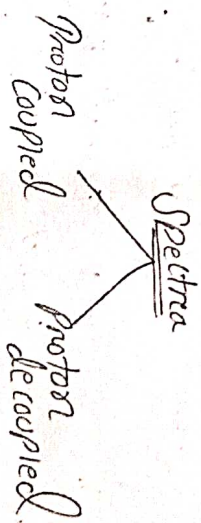
CH3 - split into a quartet according to (n+1) rule. (3+1 = 4)

CH2 - split into a triplet according to (n+1) rule. (2+1 = 3)

There will be no further spectrum splitting.

→ This technique is introduced by ¹³C-NMR
→ In ¹³C-NMR two types of spectra observed

- ① Proton coupled spectra
- ② Proton decoupled spectra



→ In off resonance decoupling instead of overall decoupling here we avoid the long range coupling and only short range coupling signal is retained. In this way the complex NMR signal is simplified.

Ex: Propanol (CH3-CH2-CH2-OH)

CH3 - quartet
CH2 - triplet
CH2 - triplet

