NMR as a Tool for Structure Determination

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ABSTRACT

Nuclear Magnetic Resonance [NMR] is a phenomenon, which occurs because of the intrinsic magnetic moments of the nuclei. These nuclei naturally occur in materials and molecules. These systems containing such nuclei, when placed in an externally applied magnetic field, can exhibit resonance absorption of energy from the electromagnetic radiation of appropriate frequency. For such a resonance phenomenon, the strength of the externally applied magnetic field and the frequency of the incident electromagnetic radiation are related through the constants characteristic of the particular nuclear species in terms of certain universal constants. This resonance phenomenon provides a potential spectroscopic tool for the determination of structural parameters in detail. The details, which this NMR spectroscopic tool can reveal, depends on the extent to which the advanced instrumentation techniques are availed in the detection of resonance signal, in the acquisition of spectra and in further processing the spectral data. The greater the incorporation of such technical advances, the more seems to be the benefits in utilizing this tool for structural determination. In turn, the better the instrumental provisions, the more seems to be possibility of designing new NMR techniques with the better insights in the theoretical understanding of the NMR phenomenon. This seem to provide a perennial cycle that the improved understanding puts demand on the instrumentation to be improved, and technology ensuring the necessary instrumental criteria provides even better insights into the NMR phenomenon resulting in new experimental schemes for availing the Nuclear Magnetic Resonance spectral features. The NMR technique being a tool for structural studies would be dealt with in this article. The essential criteria would be enlisted with illustrative applications and the specialty of this technique for structural study would be emphasized. However, it is not intended to provide exhaustive enumeration, as the coverage to such an extent cannot be contained within the purview of this only article. Thus the ***Scope*** *of this contribution is to appeal to beginners in Spectroscopic Methods who would want to gain more specialized skill in NMR. Thus the entire article has been made to be an elementary reading, at the same time and appropriate places references have been included as superscript which give a lead into the specialists' considerations. Every section consists of all elements, in such a way that every succeeding section provides an elementary reading of further details on the basis of the contents of the previous section. A few of the figures have been made out to be examples for learning the simulation techniques in spectroscopy. The References and Suggeted reading include important contributions of the some of the early original investigators to the most recent updates on the Internet webpages and online service facilities in NMR.*

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1. INTRODUCTION

Nuclear Magnetic Resonance [NMR] has been found to be a possible spectroscopic tool for the determination of crystal Structure and molecular structure[1]. The nuclei can resonate at their characteristic frequencies in the radio frequency [RF]range of the electro magnetic radiation spectrum when placed in a specified magnetic field. This frequency can be set in the NMR spectrometer, which is capable of transmitting electro magnetic radiations to the nuclear spin system. The sample containing these nuclei can be placed in the Magnet of the Spectrometer system with the magnetic field strength set to the corresponding value. The choice of a particular nuclear species for NMR studies depends upon the specific requirements of the molecular or crystal system (which may contain several nuclear species within itself as constituents) to be studied. From this point of view, the nuclei studied are, most often, ^{1}H, ^{13}C, ^{31}P and ^{15}N. Spectrometers have become available[2] with the provision for studying these nuclei by the NMR technique. When it is the study of protons [^{1}H] in crystal/molecular system by the NMR technique, it is specifically referred to as PMR studies, which stands for Proton Magnetic Resonance, provided the context is familiar enough to not confuse with the Phosphorus Magnetic Resonance. The term "CMR studies" is not uncommon when the resonance observed is that of ^{13}C nucleus. The **Table-1** reproduces the relevant characteristic properties of these nuclei and the corresponding Nuclear Magnetic Resonance frequencies, all at the same given magnetic field strength at which the Spectrometer Magnet system has been set. The prepared sample would be placed inside the sample-coil where the sample can be exposed to the RF radiation. This sample-coil assembly is located in the probe of the NMR spectrometer and this entire probe assembly would be firmly held fixed within the Magnet bore of the spectrometer system. Inside the magnet bore a homogeneous magnetic field of the required field strength would be set up for the NMR signal to be detected.

When the Spectrometer frequency can be varied, from the value for the resonance of one nucleus, to the frequency of resonance for observing another nucleus then, it is that the NMR probe be electronically tuned for the NMR frequency. This tuning of the probe happens to be the major alteration in the settings whenever a different nuclear species [in the same sample or in different samples] is to be studied. Thus in a simple NMR experiment, there would be RF radiation at only one frequency at any given time for detecting a specified nuclear spin species in the sample. If the spectrometer system has such a probe installed that, this same probe, at a given time, can be tuned to the frequency of any one of the frequencies from the list of the Resonance Frequencies of several nuclear species, as required for the variety of Nuclear systems [the number of such nuclei can be more than the only four mentioned earlier] then, this is the instance of a Multinuclear capability[3] of the magnetic resonance spectrometer system.

There are nuclear magnetic resonance techniques, in which observations are made by applying RF radiations at more than one frequency simultaneously, at the given magnetic field strength. This is the requirement for detecting two or more nuclei of the sample at the same time by irradiating at two or more nuclear magnetic resonance frequencies[4]. Thus when radiations at two frequencies are simultaneously applied, then it is the case of a double resonance technique**[5]**. When three radiations are present, it can be the triple resonance studies. In general, this technique is included under the class of multiple resonance techniques. Further, a double resonance technique could be homo nuclear double resonance when two proton resonance lines, within the PMR spectrum of the same system, are irradiated. It would be a hetero nuclear double resonance technique, if the two simultaneously applied frequencies correspond to two different nuclear species of the same sample under study. ^{1}H and ^{13}C combination is typical, and it is the most familiarly used hetero nuclear double resonance technique.

The detection technique and the associated requirements of the Electronic & Instrumentation have made possible another way to classify the NMR experimental techniques. These are the Continuous Wave (CW) RF experiments and the Pulsed RF experiments **(Fig.1).** The operation of the Spectrometers with these two different features can be difficult without adequate training. An assiduous practice with sound knowledge of NMR phenomena-the principles and the theoretical basis are the prerequisites besides familiarity with the spectrometer operating principles, to be versatile with the applications of NMR technique for structure determinations. In both, the CW and Pulsed, techniques there are corresponding multiple resonance techniques in use**[6a]**.

The most recent advances in NMR technique**[7a]**, particularly the NMR imaging and its pervasive applications in the clinical practices do have the basis from the structure determinations, but the present day advanced applications would appear too remote from the grass-root structure determination aspects.

The structure determination**[8]** entails the following broad considerations about the system (the sample or specimen as it may be referred to) under study using the available tools. Out of these tools NMR spectroscopy is a tool which is the topic in this article. Most of the time, before bringing the sample for the detailed structural considerations of the constituents, the sample would have been well characterized for its authenticity, and in particular, with respect to its source, purity and the molecular formula of the molecular system which is a constituent in the sample. This enables the choice as to which of nuclear species contained in the system would be most suitable for study by NMR technique for the required structural information. In the case of structural studies of crystals, this would be mostly to supplement the information known from X-ray diffraction technique, essentially the locations of the nuclei, and hence, the locations of the corresponding atoms in the unit cell of a single crystal or the location of atoms which are substituting the regular atomic constituents at few places, for example, as in the case of doped materials. As it would be evident, it is all mainly the geometrical aspects for determining the relative positions of the atomic constituents. In other words, it is the seeking after the situational inter nuclear and intermolecular distances. These considerations come under the realm of solid-state NMR studies where the un-averaged anisotropic interactions provide more elaborate structural information.

When it is the question of molecular structure**[9]**, whether it is in the solid state, liquid state or gaseous state, the study entails the seeking of information on the relative positions of atomic nuclei which in the bonded situation thus making up the molecule. Further inferences could be on providing explanations as to why the respective locations are preferred by the atoms in the molecule, and, how the characteristic properties of the molecule are dependent on such fixed locations that the atoms prefer to hold within the molecule. These are typically the concerns of the nature of the chemical bonding in molecules and, in turn, the study of molecular electronic structure.

The molecule could be a small molecule (molecular weight typically of the order of 10 to 1000) which is a chemical compound taken up as sample for the study. On the other hand, it could be a large macromolecule; a polymer[7c] or a biologically important molecule[7b]. In all these cases the task is to determine all the necessary details and exhaustively cover all the relevant atoms so that there are no ambiguities in the conclusions from the study.

With this broad based outline provided till now on the kind of queries addressed to in structure determination, in the following section, the relevant elements of the NMR spectroscopic tool required for structural studies would be enlisted with the description of the salient features of NMR technique which can be effective.

2. ELEMENTS OF NMR SPECTROSCOPY

The basic equation which governs the occurrence of Nuclear Magnetic Resonance is given by: either $\mathbf{h\,v = g\,\beta\,H}$ **----- Eq.1(a);** or $\boldsymbol{\omega = \gamma H}$ **----- Eq.1(b)** where, in these equations, **H** is the intensity of the externally applied magnetic field (the field strength) in units of **Gauss**; **v** is the frequency of electromagnetic radiation (usually in the radio frequency [RF] region) in units of **Hertz [Hz]** with **1Hz=1 cycle per second [cps]**; **ω** is the angular velocity in **radians per second** corresponding to the frequency **v** defining the **ω** in terms of the frequency by $\boldsymbol{\omega = 2\pi v}$; **β** is the nuclear Bohr Magneton; **g** is the nuclear **g–**factor and **γ** is the gyro magnetic ratio for that nucleus. The above equations 1(a) and 1(b) can be derived starting form the relation between the magnetic moment **μ** of the nucleus and the intrinsic spin angular momentum **I** of that nucleus as given by: $\vec{\boldsymbol{\mu}} = \boldsymbol{\gamma}\hbar\vec{\mathbf{I}}$ **---- Eq.2** with $\left|\vec{\mathbf{I}}\right| = \sqrt{\mathbf{I(I+1)}}$ the symbol **I** under the square root is the spin quantum number of the nucleus. The magnetic moment $\vec{\boldsymbol{\mu}}$ can interact with the externally applied magnetic field as governed by the equation for the Potential Energy **P.E. =** $-\vec{\mu}\cdot\vec{\mathbf{H}}$ **-- Eq.3.** Therefore, the nucleus tends to get aligned along the magnetic field direction. However, there are quantum restrictions on the allowed values for the component of $\vec{\mathbf{I}}$ (the nuclear angular momentum vector) measurable along the specified direction. Hence, the component of nuclear magnetic moment correspondingly has certain discrete values along the specified direction. These restrictions result in the different discrete energy levels for the nuclear spin system. Depending on the criteria of the quantum mechanical selection rule, transitions can be caused between a pair of the discrete energy levels when the electromagnetic radiation of the right frequency and appropriate polarization is applied to the spin system in the magnetic field. For a set of values of **H** and **v** as given by equation 1(a), the electromagnetic radiation must be polarized in the plane perpendicular to the magnetic field direction for inducing observable transitions.

If a small molecule containing protons is chosen for the proton nuclear magnetic resonance, the possible features of the PMR spectrum would depend on the following factors. If this molecule has **‘n’** number of protons, and, if the sample consists of **‘N’** number of such molecules (all identical), then the sample would account for the presence of **‘n × N’** number of protons. That is the system consists of **‘nN’** protons by way of the **n** protons per molecule, for each of the **N** molecules. If all these protons, every one of them, have the same resonance frequency at the applied field **H** in which that sample is placed, then, all the protons will exhibit resonance at the same field value for the same applied electromagnetic RF radiation frequency. This is because the set of equations **1(a)** and **1(b)** do not contain any terms or factors that would differentiate one proton from any of the other protons in the sample.

The differentiating factor in the NMR studies can arise, because the protons present within a given molecule are not all in the same electronic surrounding due to the distinctly different nature of chemical bonding, of the protons, to the atoms to which they are attached in the molecule. Thus the molecular electronic structural variations cause differences in the induced magnetic fields at the site of a given nuclei in a molecule. If these variations in the magnetic fields at the nuclear sites within the molecule are taken into account, and, if the nuclei in the molecule have all distinctly different resonance frequencies, then, the molecule can give rise to **n** number of distinctly different resonance signals corresponding to the number of protons present per molecule. The capability of a nuclear magnetic resonance spectrometer to detect and display the **n** distinct resonance signals is referred to as the **“resolution”** specification[10] for the spectrometer. If the spectrometer cannot detect the differences distinctly, then there can be overlapping of the resonance lines. This means more lines will tend to merge and appear as one line. If more than one proton contributes to the signal around a frequency then, this may appear as a resonance line with larger intensity than the resonance line for a single proton. This would be stated as one of the resonance lines being more **“intense”** than another line in the NMR spectrum. The intensity of the detected resonance line (signal) in NMR spectroscopy is usually obtained by **“integration”** procedure. The integrated value for each one of the NMR line in the spectrum is the intensity of the line and this would be indicative of the number protons contributing at a given resonance value in the spectrum. This in turn leads to the **‘sensitivity’**[10] of the spectrometer, by which, it is specified, as to the minimum number of spins required in the sample, which can give rise to a observable NMR signal in that spectrometer. There are possibilities that the protons (nuclei) having different resonance frequencies do not get resolved, but result in broad single lines in the spectrum. Or, the molecular electronic structure may provide for the same contributions to the induced fields at two different proton (nuclear) sites. Such nuclei will then resonate at the same frequency.

Having considered the protons in the same single molecule, the next query would be whether there can be any influence of the other molecules in the system (inter molecular effects), on the resonance of the protons of a given molecule. If the study is in liquid state (usually solutions) or in gaseous state most of the time, the concentrations can be maintained at such low levels, that any interaction from any neighboring molecules becomes negligible. Thus, this ensures that the entire spin ensemble of the sample can be considered as made up of spins located in different molecules, all the molecules being identical and every one of the identical molecules being completely independent from any of the other molecule in the system. In solid state, the studies are not usually on any such dilute spin systems and there are efforts to understand solid-state NMR studies as an exclusive topic of the NMR spectroscopy. It is this solid-state NMR aspect, which are pertinent for the study of crystal structures with the NMR techniques.

A simple illustration is given in **Fig.2(a)-(d),** of how the nuclei within the molecules can be differentiated by NMR on the basis of the nature of bonding within the molecules. These are ^{13}C NMR spectra, not from a spectrometer, but, Calculated using software, which can calculate the resonance frequency differences within the molecule for the Carbon nuclei and display the spectrum constructed from the calculated values. At this introductory stage, adding the following could be a digression. But, here, it may be found to be an incentive for the reader who is a beginner. This would serve as an incentive because, even without many of the details at this moment, these illustrations can easily show, as to how; the recent advances have made this NMR tool a potential device for structure determination. The actual use would require greater appreciation of the intricacies of the NMR technique that would be the discussion in the remaining part of this article. What has to be appreciated here is that there are four molecules drawn and their corresponding calculated ^{13}C NMR spectra are given. These have been calculated using a powerful geometry optimizing Software PROGRAM called COSMOS. This program calculates also the chemical shift (which will be explained in the later part of this article) parameters which indicates the relative line positions in the spectrum. Thus in all the spectra the carbon of the methyl group occurs at 23.5. The CH_2 (methylene group) carbon nucleus occurs at 35.196 in 2(a) but in 2(d) it occurs at 62.155. This large difference is because this carbon in 2(d) is attached to Oxygen atom but in 2(a) it is attached to a carbon atom. If a carbon atom is bonded to a Oxygen atom as in 2(c) and 2(b) not the same way as in 2(b) then these atoms occur at respectively 152.5 and 146.3 which are much larger than the 62.15 of 2(d) and 35.6 of 2(a). These outputs to obtain from the soft ware does not require more than 20 minutes since the molecules can be drawn with a Structure Editor and then selecting from the menu for the Geometry optimization and running paves the way further similarly to calculate the NMR parameter (**chemical shift**)[19a] and display also as spectral plot. Thus by drawing the molecules for the several variations in the substituted groups and atoms, the carbon resonance line shifts can be seen associated with the corresponding molecular bonding nature and the electronic structures. The interaction with the external magnetic field is the responsible factor for what has been described until now. In presence of the magnetic field, when the spins have aligned and (are in thermal equilibrium), then, there can be ***time-independent*** interaction among the nuclear spins themselves which can cause changes in the energy levels in addition to the Zeeman splitting. This feature will be observable in the spectra as "**spin-spin coupling"**[19b] effect with characteristic coupling constants indicative of the structural aspects in the molecule(these features are absent in conventional CMR spectra and hence, in

Fig.2(a)-(d) as well. The reason for this would be evident from the discussions in subsequent sections). The calculated typical PMR (proton spectrum) of **Fig.3** exhibits the above features of spin-spin coupling with chemical shift consequences.

The alignment of the spins with respect to the magnetic field, soon after placing the spins in the magnetic field, does not happen instantaneously. In the absence of any magnetic fields in the Laboratory, the spins in the system (in a diamagnetic sample) are, directionally, in a non-preferential state and the magnetic moments of the nuclei do not have any specific orientation. The spins in such a thermal equilibrium distribution in the absence of magnetic field does not have the necessary prerequisite to exhibit absorption of energy from electro magnetic radiation. Thus, the magnetic field will have to be applied to the spin system wherever it has been placed or the sample must be introduced into the region where the magnetic field is already present. In any case, the sample containing the ensemble of nuclear spins gets an exposure to the magnetic field at the time when it has not been exposed to that magnetic field before. Now, the spin alignment with respect to the direction of external magnetic field begins. Then, for it to reach a thermal equilibrium in the external magnetic field takes some time, which is significant and measurable in most of the NMR samples. Depending upon the nature of the sample, this time can be from few milliseconds to several hours or even days. This characteristic time of the spin system is referred to as the **"spin-lattice"** relaxation time[6b] symbolized as $\mathbf{T_1}$ relaxation time **(Fig.4a).** At any time when the spin system has to redistribute (*from a **non-equilibrium** distribution*) its **populations** (*the number of spins in a particular discrete energy level*) in the energy levels, then this characteristic relaxation time would be encountered in the process of the reaching an equilibrium under the different state for the spin systems. This redistribution among the energy levels due to the magnetic field (Zeeman splitting) is reached with a characteristic "relaxation time" which mostly depends on the surrounding of the nucleus with regard to the presence of other nuclear moments. If in a molecule there are other nuclei closer to the resonating nucleus are present (as in the CH_3 above there are 3 protons) then the resonating nuclei ^{13}C has a much faster relaxation time than for example in the case of a $^{13}C=O$. Thus, a "**relaxometric"** method also can be envisaged and it can be supplementing significantly to the "chemical shift" and "spin-spin coupling constant" data for structure determination. This is particularly useful in CMR. An example of such an application in PMR is depicted in **Fig 4c.** The utility of the "relaxometry" is evidenced in solid-state NMR applications[15] as well.

There is another kind of relaxation mechanism called **"spin-spin relaxation"** (symbolized as $\mathbf{T_2}$**)** which gets a preferential treatment in NMR of solids, but it may not have a direct significance for structure related queries in HR NMR in liquids. Hence this '$\mathbf{T_2}$ ' would not be considered in this article in much detail. It suffices to mention that this spin-spin relaxation with the characteristic time $\mathbf{T_2}$**,** contributes significantly in devising pulsed-NMR experimental techniques which can critically distinguish ambiguous structural situations, and, techniques to overcome the instrumental artifacts which can dominate even while the NMR spectrum, as obtained form the spectrometer, contains abundantly overwhelming structural information.

At this point digressing to **Fig 5b** could be a useful exercise for students to acquaint with spectroscopic data analysis. Fig.5b indicates the use of a MS Excel Application for simulating the experimental spectra with a probable line shape. The simulated two-line pattern of resonance lines illustrates what is a **"well resolved"** spectrum and what are the consequences of overlap in the limit causing a coalescence of the two lines. A similar coalescence phenomena in NMR occurs when a given nucleus exchanges position between two sites in the sample as illustrated in **Fig. 5c.** The resonance frequency might be slightly (but measurably) differing in the two positions where the same nuclei would be found alternately. If this difference in resonance frequency is **$\Delta\omega$ and if the 'dwell-time' or the 'life-time' of the nuclei in the sites before exchanging to another site is τ_e then the NMR spectrum of such a system would consists of NMR signals from both the sites distinctly only if $1/_{\tau e}$** $<< \Delta\omega$. If the **τ_e** (exchange rate) is varied by changing the temperature of the sample, then by an increase of temperature the **$1/_{\tau e}$** can be made very large compared to the resonance frequency difference '$\Delta\omega$'. At such a temperature the two lines corresponding to the two different sites would coalesce to a single resonance line at an average value for the resonance frequency. The broadening that occurs in the NMR signals is indicative of the changes in the **T_2** (transverse) relaxation processes mentioned earlier. This has the consequences of finding such features in the NMR spectra is to indicate the structural positions where the possible exchange phenomena can occur indicating "labile" nuclear sites. In **Fig.4a** [parallel stacked-plots] and **Fig.4b** [serially stacked plots], calculated relaxation (longitudinal relaxation **T_1)** curves are given graphically and these again can be exercises for using the Information technology tools to make simple simulations which makes the student be familiar with the trends and the equations to describe them. There are instances such familiarity particularly the use of the IT tools for such calculation can make the structure determination extremely simple.

3. INTERACTIONS OF NUCLEAR SPINS AND SPECTRAL PARAMETERS

The equation 1(a), as it was pointed out earlier, does not have any terms that can differentiate nuclear spins on the basis of their specific location and occurrence within a molecule which typically may constitute the spin ensemble. The equation can be rewritten by including specifically the terms which distinguish the spins on the basis of the nature of the interactions characteristic of the given nuclear spin site. These interactions can be characterized by a constant indicating the extent of the specific interaction at a specified site. Even if another spin has contributions due to interactions of similar nature, the strength of the interaction may be different at different nuclear sites, and these differences may consequentially appear in the spectrum enabling the structure of the matrix (molecule/lattice) in which the nucleus is situated. This is a general form for including such site-specific differences in the basic interaction, which is the interaction with the external, strong and steady Magnetic Field. Compared to this term (referring to the corresponding energy of interaction) all the site-specific interactions are usually small, and in this sense theoretical treatments can specify a **"High Field"** approximation for conveniences of obtaining simple equations for evaluation. In this section the

nature of the various site-specific interactions, with the associated **constants** as the spectral parameter, would be enlisted for the benefit that, in the further sections, the examples of applications can refer to these spectral parameters for determining structures.

The nature of the interaction that leads to shielding of nuclei is explained further in **Fig.5a** These descriptions account for the shifts, which can be observed with respect to the bare nuclei which do not have any electron systems surrounding. Since referencing the nuclear system with respect to bare nuclei, even though possible, but, is not practicable for the conveniences of regular spectral measurements, a chemical molecule which is relatively inert chemically and has a single-line NMR spectrum is used as reference compound and added to all the samples. The single reference compound line can be set to zero, or, to a certain specified value. The other resonance line positions can be measured relative to the reference line. Such values of shifts measured from the standard reference line are termed the **chemical shift**[18a] values. Hence, an unknown electronic surrounding around the nuclei can be ascertained, by measuring these relative shielding values which are called chemical shifts, and by the comparison with previously measured chemical shifts (as in **Table-4**) for known electronic surrounding for such nuclei.

As explained earlier, for any particular nucleus, the resonance frequency value calculated by the equation 1(a) corresponds to the NMR signal of a **"bare nuclei"**, which is not surrounded by any electrons. An addition of electron into its surrounding starts contributing by induced fields at the nucleus, which is resonating. Addition of electrons and hence the presence of electronic charge cloud induces magnetic fields at the nucleus because of the fact that the electrons also gets placed in the External Magnetic field where the nucleus is. If we consider only the electron charge cloud without any unpaired electron spins, typically diamagnetic systems, then the induced fields are in the direction opposite to the direction of external magnetic field. Thus the nucleus would now be exposed to Field strength some what less than if the electrons are absent. Since the field values at the nuclear sites are reduced by the presence of electrons, the electrons are said to be Shielding the nuclei from the external field. Thus to the equation 1(a) a term corresponding to this shielding is added. The effect of electron is given a value as shielding constant and it is subtracted from the strength of the externally applied field indicating the shielding nature of this interaction. Hence the Equation 1(a) is now written as: $\mathbf{h\nu = g\beta(H - H^{/})}$ where $\mathbf{H^{/}}$ refers to the strength of the induced field in the opposite direction to $\mathbf{H}$. The induced field being caused by the External field its magnitude becomes proportional to the strength of the external field if the other criteria of the samples are held the same. Hence, it is conventional to write $\mathbf{H^{/} = \sigma \times H}$ where $\boldsymbol{\sigma}$ is the shielding constant. Then equation 1(a) is rewritten as $\mathbf{h\nu = g\beta H(1-\sigma)}$ ---**Eq.4**. The $\boldsymbol{\sigma}$ now represents the site-specific shielding effects and its value reflects the electronic structural surrounding of the nucleus. This $\boldsymbol{\sigma}$ is not always a simple scalar constant, but in general a second rank tensor. In solution state NMR Spectra, only the trace of the tensor appears in the equation, which is a scalar number. Only when the situation demands the full significance of the Shielding Tensor would be referred to in this article. Otherwise, the relative shielding constant values would be used to illustrate the utility in the NMR structural studies.

For Proton Magnetic Resonance Spectra, the chemical compound 'Tertra-Methyl Silane' (**TMS**) with molecular formula **$Si\ (CH_3)_4$** is the standard reference compound. **Table-2** contains a list of compounds useful as standard references in NMR spectroscopy. This molecule has 12 protons and because of the symmetrical location in the molecule, all the 12 protons have the same resonance frequency [*a set of 12 equivalent protons*]. Hence, the proton NMR spectrum of TMS consists of a single line corresponding to the resonance of the 12 protons because of which it gives a strong single line NMR signal even when its concentration is small. This compound is chemically relatively inert. It is a volatile liquid at normal temperature and pressure. It is easily miscible with most of the organic solvents used in NMR spectroscopy namely, Chloroform $CH\ Cl_3$, Acetone $CH_3\ CO\ CH_3$, Carbon Tetrachloride $C\ Cl_4$. Thus referenced NMR spectra can be easily obtained, by adding a small amount of TMS to the sample solution as an external reference to the actual molecule of interest. The CH_3 of the TMS have the most shielding electronic surrounding as compared to the electronic surrounding of the protons many of the other known chemical molecular compounds. Therefore, this TMS, added as an external reference, can yield a reference NMR line that can be reliably located at one end of the observed proton NMR spectrum even when an unknown structure of a chemical molecule has to be determined. In the chemical shift **'δ'-**scale, TMS line is assigned the value '**δ = 0'.** The protons from other molecules with several variety of different electronic environment are found to result in NMR signals all on one side of this line and can be assigned a positive numerical value proportional to the deviation [*chemical shift*] from the δ=0 line from the TMS. Mostly, no NMR line occurs on the negative side of such a spectral chart (Fig.6).

Such shielding (chemical shift) due to the changes in electronic structure around the protons can be measured in frequency units. As known now for the case of protons the maximum range for this shift measured in frequency units are found to be 1KHz in a 100MHz (Proton) NMR spectrometer, 2KHz in 200MHz spectrometer, 3KHz in 300MHz spectrometer and so on. From this it should be obvious that the Spectrometer magnetic field would be different for these spectrometer systems. In order to express the shielding and Chemical Shift in a scale which is independent of the Spectrometer frequency, the following definition is convenient. Since in each one of the above, dividing the range of chemical shift by the spectrometer frequency yields a dimensionless number 10×10^{-6} , this range is termed as 10 ppm [Parts Per Million] units. It is found that when the chemical shift values are measured in such 'ppm' units, for given sample the resulting NMR spectrum has the same spectral chemical shift value assigned irrespective of what the spectrometer frequency was [independent of the operating frequency of the spectrometer] and at which Magnetic Field Strength the spectrum was obtained. This characteristic of the Shielding Effect will be further stressed later while emphasizing the importance of seeking Spectrometers, which can operate at Higher Magnetic Field Strength; consequently, for a given nuclear species, at Higher spectrometer frequencies.

The next important interaction to be considered is the "**spin-spin interaction**" which again is the time-independent [as the shielding interactions] and manifests in a NMR spectrum of a chemical compound. Except for the fact that, the externally applied strong field provides a direction along which all the spins get quantized, there is no dependence for the spin-spin interaction on the presence or the strength of the external magnetic field. The strength of this interaction is measured by the spin-spin coupling constant from the NMR spectrum. But the spin-spin coupling constants are measured, particularly for structure determinations, only from the NMR spectra obtained in presence of strong externally applied magnetic field. All the spins are aligned along the magnetic field direction and the corresponding nuclear magnetic moments experience an additional magnetic field due to the presence of the neighboring nuclear magnetic moment. This spin –spin interaction causes a splitting of the energy levels in addition to the splitting due to the Zeeman interaction (the interaction of the spin with the external magnetic field**.** Depending upon the number of neighboring spins with which a given spin interacts, the number of lines into which the NMR line splits can vary. This results in multiplet line structures in NMR spectra, with characteristic intensity ratio of the lines. The distance of separation observable within the multiplet lines yields the spin-spin coupling parameter from the NMR spectrum.

Mainly, there are two different and characteristic ways by which this spin-spin interaction can occur in the spin systems. The first type of spin-spin interaction is the “through” space or the “direct”[18b] spin-spin interaction. This arises because of the possible extent to which the magnetic dipolar field due to one nuclear spin magnetic moment can be affecting the neighboring nuclear magnetic moment at a different site. Considering the point-dipoles to be representing the nuclear magnetic moments, each pair of nuclear moments can be related by a point-to-point distance **‘r’** and the corresponding inter nuclear axis can be assigned a definite angle **‘θ’** that it subtends with the direction of the external magnetic field. The ‘through space’, ‘direct’ dipole-dipole interaction depends on the distance **‘r’** and the angle **‘θ’,** which can be the target parameter to measure from NMR spectra for structural measurement. The PMR studies on single crystal of Malonic Acid how the direct dipole-dipole interaction between the two methylene protons results in the measurement of the H-H vector direction to be 6±2° tilted away from the perpendicular to the c-c-c plane. Also the HR PMR measurement on the same sample reveals the anisotropic shielding tensor properties. This Wideline (*In solids the NMR lines are much broader than it is in the case of liquids. Because of this larger widths the NMR lines are wider and hence the name Wideline NMR*)and High Resolution PMR study (*HR PMR study in Solids requires specially designed pulse sequences to average out the anisotropic line-brodening interactions among the spins*) on the single crystal of the Malonic acid proves[18d] the importance of NMR technique for structural measurement. As pointed out in the earlier section, this is under the realm of the solid-state NMR studies.

The other type of spin-spin interaction is the **‘indirect’**[18c] or **‘through-bond’** interaction which is characterized by a spin-spin coupling constant **‘J’.** This is also referred to as a ‘**contact’** interaction contrasting with the dipole-dipole interaction which characteristically requires a well defined distance of separation between the two spins **‘r’,** measurably. The through-bond interaction is necessarily mediated by the electron clouds in the bonding region. This interaction requires that the nuclear magnetic moment should affect the electron charge cloud around it, and, this effect in turn is transmitted to the neighboring bonded nucleus by way of an induced magnetic field change. This type of transmission requires that the electron charge cloud has an ‘s’ orbital characteristics, which has a non-vanishing charge density value at the site of the nucleus. Hence, the term ‘contact’ interaction.

Because of these characteristics of the 'indirect' spin-spin interaction, measuring the 'J' values for different spin pairs indicate the variation in the electronic structure as much as the chemical shielding (shift). But, the dependence of the **J** and **σ** on the given electron cloud structure is not the same even if it is in the same molecular system. Hence, these two parameters, together, can span the electronic structures to a greater detail advantageously than any one of the parameter alone.

Ethanol (Ethyl alcohol) has the molecular formula $\mathbf{CH_3\ CH_2\ OH}$. The PMR spectrum of this compound contains three signals at the positions corresponding to the chemical shift of CH_3 protons (1.13 ppm), - $\mathbf{C\underline{H}_2}$ protons (3.61ppm) and the $\mathbf{–O\underline{H}}$ protons (5.24 ppm). The number of lines (signals) mentioned above is without taking into consideration the possible splitting due to the spin-spin interaction of the $\mathbf{C\underline{H}_3}$ protons with - $\mathbf{C\underline{H}_2}$, and the - $\mathbf{C\underline{H}_2}$ protons with $\mathbf{C\underline{H}_3}$ and $\mathbf{–O\underline{H}}$ protons and the $\mathbf{–O\underline{H}}$ protons with - $\mathbf{C\underline{H}_2}$. When integrated for the intensities, these lines would have the integration height values indicating intensity ratio of 3:2:1. Such a spectrum is obtainable when the spectrometer does not have high enough resolution and produces only three lines above for the PMR of ethanol. This is a moderately resolved spectrum since, chemical shift differences are resolvable, but not the spin-spin splitting patterns. The line width in such moderately resolved chemical shift patterns could be of the order of 20-30 Hz. This would appear to be of the order of 0.5 ppm width in a 60MHz PMR spectrometer. The resolution of the spectrometer can be improved by improving the magnetic field homogeneity of the of the magnet system. This process of improving the field homogeneity is called the "shimming" of the magnet system. The High Resolution Magnet Systems can have the homogeneity good enough to yield spectra with resolution of the order of 0.2Hz. Such resolutions are achieved with any kind of stable magnets, independent of the steady magnetic field value for which the magnet is set for and hence independent of the operating frequency of the spectrometer. Such a spectrometer is refereed to as the High Resolution [**HR**] NMR Spectrometer. The spectrum of ethanol in presence of trace of acid in the medium, and from a High Resolution spectrometer would result in a triplet centered at 1.13 ppm for the CH_3 protons because of its coupling with the CH_2 protons. The three lines triplet would have the intensity ratio 1:2:1. The CH_2 protons would be split into a quartet (intensity ratio 1:3:3:1) centered at 3.61 ppm. The four lines arise because of the coupling of the CH_2 protons with the three protons of the methyl group. The magnitude of the spin-spin splitting is 7Hz. The neat ethanol sample would contain in the PMR spectrum the spin-spin interaction of the OH protons also and because of its coupling with the CH_2 protons there would be a triplet centered at 5.24 ppm with coupling constant value of 4.5Hz. Each of the four lines in the quartet of the CH_2 protons, in this case, would be further split into sets of doublet lines due to the presence of one proton of the OH group. A similar spin-spin splitting for the case of PF_3 appears in **Fig. 7a** and **7b**. This is a case of hetero nuclear spin-spin splitting between the ^{31}P and the ^{19}F nuclei due to the coupling between the Phosphorus and Fluorine nuclei as evidenced in their respective NMR spectra. The multiplicity pattern due to the interaction with a given set of nuclei "**n**" in the neighborhood can be ascertained by well-defined relation relating the resulting number of split-lines to the value 'n' concomitant with the requirement of well specified intensity ratios for the resulting multiplicity patterns **(Fig. 7c).**

As it is evident, the group of 3 protons in the **$-CH_3$** part of the ethanol do not have any spin-spin splitting features manifesting in the NMR spectrum which can be attributed to the spin-spin interaction among the three methyl protons themselves. That it is a group of three protons can be inferred only by the multiplicity pattern it causes in the NMR of neighboring bonded protons. Thus, this set of three protons of methyl group is known among the category of equivalent set of protons. Similarly the two protons of the **CH_2** group form a set of equivalent protons among which the splitting cannot be seen in the spectrum. The main criterion for the set of equivalence of the protons is that they all have the same chemical shift values being present in the same electronic environment due to the nature of bonding in the molecule. Thus it is necessary to classify the spectrum on the basis of these patterns that can be observed depending upon the number of equivalent protons with a particular value of chemical shift, and the neighboring equivalent protons interacting with each set of equivalent protons. Even though the multiplicity patterns are governed by simple relations, these relations are simple only under certain approximations. If two different sets of equivalent protons are interacting with a specific '**mutual'** spin-spin coupling constant value for **'J' (in units of Hz),** and if the two equivalent sets have their corresponding chemical shift values are **δ_1** and **δ_2 ,** then, the spin-spin splitting patterns have simple correlations only if the difference $|\delta_1 - \delta_2|$ measured in Hz **(i.e., the difference multiplied by the spectrometer frequency)** is larger than the **J** value by an order of magnitude. This means $\frac{|\delta_1 - \delta_2|}{J} \geq 10$. Then the resulting pattern is said to be a first order spectrum, which is the simplest case for interpretation. There are definite set of rules based on the theoretical considerations for characterizing the multiplicity patterns even when the above ratio is not as high. These patterns appear tabulated **(Fig-8)** as a function of the varying values of the ratio until that value beyond which the pattern remains simple enough. All these require developing a systematic set of nomenclature[11] to refer to the patterns without having all the time to show the spectra during the discussions after gaining familiarity. It is to be well comprehended that the spin-spin coupling constant ['**J**'] value measured in frequency units is independent of Spectrometer frequency, and the Chemical shift measured in ppm **δ-**scale is independent, in numerical value, of the spectrometer frequency. Thus the ratio of the chemical shift difference to the spin-spin coupling constant is dependent on spectrometer frequency [and the magnetic field] for the same sample. Thus it is possible to convert a complicated pattern into a simple pattern by taking the spectra in a spectrometer working at higher Magnetic field strength. This simple method of working at higher magnetic fields [**Fig.9]** is a simplest way of obtaining easily interpretable spectra, provided the technology permits to that limit for a given sample.

All the above considerations illustrated for the PMR spectra, have similar counter parts for the multi nuclear NMR. The possibilities for homo nuclear and hetero nuclear combinations are many and once, in principle the mechanisms are understood and by gaining familiarity with the use of NMR for structure determinations, it should be possible to realize the full potential of this tool in the varied contexts as becomes necessary. As was pointed out earlier, the protons in the various chemical environments have chemical shifts within the range of mostly 10ppm. But, the chemical shift ranges for all the nuclear species are not the same. For example, the ^{13}**C**- Carbon NMR, the resonance frequency for which is approximately ¼ th of the proton resonance frequency at the same given magnetic field, spans a range of about 250 ppm in comparison to the 10 ppm range for protons. Thus if the PMR spectrometer frequency is **100MHz** [**at 23.5 Kilo Gauss**], then 1ppm is 100Hz so that the protons have a range of **1KHz**. At this same field, the ^{13}**C** resonate at **25.6MHz** and the 200 ppm would correspond to 200 x 25.6 = **5.12KHz.**The observed chemical shift range for ^{15}**N** is about **1000 ppm**; and for ^{31}**P** the range is about **350 ppm**. The ^{31}**P** nuclei in biological samples cover a range of about **30 ppm.** Thus the sample coil tuning of the probe-system and the signal detecting would have to take into considerations such variations in ranges which are closer the Audio frequency range values of the electromagnetic spectrum, while the resonance (operating) frequencies are in the radio frequency [**MHz**] ranges. The technological advances have nowadays made it possible to have NMR spectrometers which can operate at Magnetic Filed strengths of **14.092 Tesla** which is **140.92 Kilo Gauss** values**.**

4. AN OUTLOOK ON THE UTILITY *'NMR'* FOR STRUCTURE DETERMINATION

On the basis of the nature of the interaction described and the corresponding NMR spectral features, a guideline can be worked out for interpreting the values of the parameters obtained from NMR spectra by carefully analyzing[12] the correlations between structure and the values of chemical shifts and coupling constants.

The convention in NMR spectroscopy is to choose a compound with, possibly, only one equivalent set of **most shielded** nuclei and set it as reference with zero value on the **'δ-scale'.** This is the extreme, **right most** end of the spectrum in a conventionally produced chart-paper for NMR spectra. The direction from left to right is towards higher-field resonance values; when the spectrometer frequency is held constant at a set value then the resonance field must vary depending upon the extent of shielding at a particular nucleus. According to **Eq.4,** the product **'H (1-σ)'** must remain constant if **'v'** is held constant. Whence, as the shielding of nucleus, and hence the '**σ'** value, increases from *bare nucleus* value **0**, the value of '**H'** must increase. The maximum possible shielding value 'σ_{max}' is set as chemical shift '**δ**=0', so that for **σ**=0, the chemical shift value can be at its maximum δ_{max}**.** Thus shielding must be measured with reference to Bare Nucleus (no-shielding), and chemical shift with reference to the resonance in the conventional **chemical** compound (containing typically most shielded nuclei). The direction from left to right is towards higher-field resonance values. This convention, as above, for routinely measuring NMR parameters from the spectra on chart papers obtained form the spectrometers, provides the following convenient descriptions to indicate the structural situations around the nucleus in the given sample.

When, due to the molecular bonding and the electronic structure, there happens to be more electron charge density around a nucleus (**Fig.10**), then, the possibility of diamagnetic shielding[13] effect increases. If the electron charge cloud can undergo changes in the electron-circulation characteristics (the velocity of circulation and/or the radius of circulation due to the nature of chemical bonds) then, even for the unaltered 'charge density' value, the diamagnetic shielding effect can increase with increase in the velocity of circulation and decrease in the radius of circulation. The opposite trends can be described as paramagnetic deshielding effects. Till now the nucleus had been considered *to be at the center of* (**within**) the relevant charge clouds. If the nucleus under consideration is situated in a region near by, but outside, the electron charge cloud, even then the changes in the charge cloud and its characteristics can influence the nucleus in the neighborhood. Then the reasoning must be based on the dipolar field distributions around a point dipole[14]. The considerations of whether, the point-dipole approximations can be valid for explaining the neighbor group contributions can add to the strength of the arguments for the derived structures or can act as constraints when there is necessity to restrict the possibilities of equivalent assignments. This typically is the approach while trying to work out structures of large molecules where the double resonance techniques (the nuclear Overhauser effect) provide the necessary inter nuclear distance constraints while trying to obtain optimized structures. It is possible that such types of correlations open up an endless possibility so that a structure can be solved entirely based on NMR spectral information without having to resort to any other tool.

The spin-spin interactions are much smaller in magnitude as compared to the chemical shift difference in frequency units. These interactions depend upon more critically on the nature of the molecular electronic structure **in the region** where the interacting nuclei are situated rather than being specific about **only a given nuclear site.** The possible immense structural correlations to the nature of the bonding provide detailed information with reference to the number of bonds between the interacting nuclei, multiple bond formations and, to the corresponding hybridization of the atomic orbital, which have to be invoked to account for the shapes and charge distributions due to these bonds. These are in addition to what the chemical shift information can provide.

The spin-spin coupling constants and the Chemical shift values can be correlated to result in a consistent set of assignments which fits in with the chemically feasible and favorable structures. But this requires enormous effort when the system under study is large and several sets of parameters close to one another resulting in complicated appearance of the spectrum. Typically the kind of effort required can be ascertained from the fact that certain spin-spin splitting patterns observed in NMR would require an elaborate simulation techniques to ascertain the nature of the interacting spin system and the corresponding chemical shift and coupling constants. The multi dimensional NMR techniques provide the advantage of greatly simplifying the task of correlating the chemical shifts with the corresponding possibility that a pair of nuclei with the assigned chemical shifts can in principle be coupled or not. Once it is established, that given two spins with specified chemical shifts are coupled by spin spin interactions, then the pulsed multidimensional NMR techniques provide a range of experiments which can be designed to extract the magnitudes of these coupling constants as well. These types of assignments were made conventionally by double resonance techniques namely 'spin-decoupling' or 'nuclear Overhauser effect'[5,17].

The analogous experiments in the multidimensional NMR techniques are the **"CO***rrelated* **S***pectroscop***Y"**[16a] and the **"N***uclear* **O***verhauser* **E***ffect* **S***pectroscop***Y"**[16b]**.** The correlated spectroscopy produces a spectral pattern, which correlates the chemical shifts plotted on two frequency axes (with the possibility that the chemical shifts of one axis could be from a spin system coupled with another spin system with chemical shifts as displayed on the second axis). These types of multidimensional spectra produce such information by identifiable “cross peaks” in the spectra. The experiments can result in cross peaks only for spin systems, which are coupled. Between spin systems which do not exhibit sin spin interactions in the molecular environment, do not yield “Cross Peaks” in the two dimensional spectral plots. Once it is established by the correlated spectroscopy that certain sets of spins in the systems are coupled, then the multidimensional NMR techniques have a series of experiments which can be resulting in the determination of the spin-spin coupling constant values as well. Typically what is named as **a “J-resolved”[20]** two dimensional NMR technique, along one of the axis chemical shift values of the nuclei are plotted and on the other axis their corresponding spin-spin coupling patterns only without any reference on that axis to the chemical shifts. With the possibilities of obtaining such multidimensional NMR spectra in spectrometers at high a Magnetic field strengths as 14.02 Tesla (corresponds to resonance frequency of **600 MHz for Protons**), the NMR holds promise for the application as a tool for structure determination. The Nuclear Overhauser Effect Spectroscopy can produce cross peaks in two dimensional spectra provided the two spin systems (with one system on the one of the chemical shift axis and the other systems on the second axis) are placed geometrically in such proximity (even though by directly bonding) by the stereochemical dispositions, that the direct (through space) dipole-dipole interaction which is time dependent (because of the variation of the polar angle of their inter nuclear vector) due to the molecular motions exercises an influence by relaxation mechanisms. In such event there can be a cross peak which would indicate the stereo chemical proximity, an information about the non-bonded dispositions of the spin-systems in molecules.

Even at such high fields, for macromolecules, the resulting spectra may be projecting out only certain recognizable spectral structural patterns instead of the display of discrete line spectra as is possible for small molecules. Thus besides the finger prints of spin-spin splitting patterns for spin systems within molecules, it may be possible to document finger prints of molecules which occur conspicuously as familiar fragments(**Table-3**) in macro molecules. When several of such familiar fragments are present together in a macro molecule, then the resulting spectral features may not contain any explicitly visible pattern corresponding to any of the documented[21b] single molecular fragment but a overall pattern must have to be analyzed for the constituent patterns and further into constituent spin-spin splitting structures. Thus an elaborate pattern recognition**[21a]** procedures would have to be programmed and implemented. Even though, this description seems to be that of a formidable task, propping out a question, whether it is all worthy enough or not (to spend time on this tool for structure determination), the actual situation in the practice of NMR is providing pleasingly encouraging possibilities.

The present day spectrometers**[24]** have built in automated programs to set up pulsed experiments of the type of Correlated Spectroscopy, J-resolved Spectroscopy, Nuclear Overhauser effect Spectroscopy and many more. Not only that the spectrometers can produce spectra for visual display[23], they can also store the entire spectral information as data bases convenient enough to process them with the available spectral data processing software packages in the dedicated computers. Hence all the required experimental acquisitions and the data processing options can be setup finally to yield, from the computer aided NMR Spectrometers, the final structural information as required for understanding the molecular structures and their functions. Thus the NMR in the present day is a potential tool for structure determination.

When by the studies in liquid state the NMR can reveal so much of structural information, then, the natural inquisitiveness to know about studies in solids cannot be dormant. But, in this article not much can be covered about how much more details can be acquired from solid state NMR and what are the additional aspects that have to be invoked for those advantages in solid states from the perspectives of the basic interactions discussed till now in view of the liquid state of the samples.

Basically the difference in solid state[22] is that there are no tumbling motions of the molecules and hence there are no time averages to be considered when the spin systems have dependences on the orientation of their inter nuclear axes with respect to the external magnetic field direction. Thus the anisotropy of all the interactions do not get averaged and the resulting tensor parameters of the system for the basic interactions scan the electronic structure of molecules spatially to reveal the nature of bonding precisely. To what extent the combined information wide line NMR and the high resolution solid state NMR studies can reveal about the nature of molecular packing in crystals and the effect of inter molecular shielding interactions and the inter nuclear distances can be ascertained by looking through the discussions in some of the typical solid state NMR studies and the references there in. In fact by grasping the possibilities with the HR NMR in liquid studies it is only a matter of some more reading of the nature of the un-averaged interactions which would make it evident what the solid state NMR studies holds for structural studies. Along with the advances and achievements in the experimental aspects of NMR, the theoretical calculations of the NMR parameters are providing a supportive basis for the experimental findings and the gain there by is getting the right clues to improve the theoretical formalisms.

REFERENCES

1. a. H.S.Gutowsky, *Physical Methods in Organic Chemistry,* 3rd Edition, Part 4, Ed., A.Wessberger, Vol.1 of *Techniques of Organic Chemistry* Interscience, New York (1960).
   b. J.C.Martin, *Journal of Chemical Education,* Vol.38, (1961) pp286
   c. A. Carrington and A.D.McLachlan, *Introduction to Magnetic Resonance,* Harper and Row, New York 1967.
   d. N. Bloembergen, *Nuclear Magnetic Relaxation,* Benjamin, New York (1961)
   e. E.R.Andrew, *Nuclear Magnetic Resonance,* Cambridge University Press, Cambridge (1955).

2. a. D.G. Howrey, *Journal of Chemical Education*, Vol.48, A327 (1971)
   b. M.C. Martin, J.J.Delpeuch and G.S.Martin, *Practical NMR Spectroscopy,* Heyden, London (1980).

3. R.K.Harris, *Nuclear Magnetic Resonance Spectroscopy,* Pitman, London (1983).

4. A. Abragam, T*he Principles of Nuclear Magnetism,* Oxford, Clarendon Press (1961).

5. W. Von philipsborn, *Methods and Applications of Nuclear Magnetic Resonance,* Angewandte Chemie, International Edition, Vol.10 , (1971) pp 472-490 –in particular an instance has been cited on page 486 as to how the 'nuclear overhauser effect' was the only possible technique to characterize isomeric azabicyclo (2,2,2) octane in a mixture, in which, it was not possible to isolate the two isomeric forms from one another.

6. A.Derome, *Modern NMR Techniques for Chemistry Research,* (Organic Chemistry Series, Vol.6) Pergamon Press, (1987).
   a. Chapters 1 and 2.
   b. Chapter 4, Section 4.4.

7. K.H.Hauser and H.R.Kalbitzer, *NMR in Medicine and Biology: Structure Determination, Tomography, In Vivo Spectroscopy,* Physics in Life Series, Springer-Verlag, Berlin-Heidelberg-New york (1989).
   a. Chapter 4 *NMR Tomography.*
   b. Chapter 3 *NMR Spectroscopy of Bilogical Macromolecules.*
   c. M.E.A Cudby & H.A. Willis, *Nuclear Magnetic Resonance of Polymers,* Annual Reports on NMR Spectroscopy, Vol4 Ed., E.F.Mooney, Academic Press, New York (1971).

8. a. E.D.Becker, *High Resolution NMR,* 3rd Edition, Academic Press, New York (199)
   b. C.A. Fyfe, *Solid State NMR for Chemists,* CFC Press, Guelph, Ontario CANADA.

9. a. L.M.Jackman, *Nuclear Magnetic Resonance Spectroscopy*, Pergamon Press, New York (1959).
   c. E.Fluck, *Die Kern Magnetische Resonanz und Ihre Anwendung in der Anorganische Chemie,* Anorganische und Algemeine Chemie in Einzeldarstellungen, Band V, Springer Verlag, Berlin (1963).

10. A.Derome, as in ref.6 above. Chapter 3. *Basic Experimental Methods.*
11. B.Dischler, *Classification and Analysis of NMR Spectra,* Angewandte Chemie, International Edition, Vol.5 No.7 (1966) PP 623.

12. Russel S.Drago, *Physical Methods in Inorganic Chemistry,* Chapter 8, 'Nuclear

Magnetic Resonance Spectroscopy', (1965) pp 239-314.
Interpretation of NMR Spectra, an On line Internet document at URL
http://www.chem.orst.edu/ch361-464/ch362/nmrintro.htm

13. a. As it has been enumerated in Table-3.
    b. As illustrated in Fig.10 in accordance with Table 4.

14. H.M.McConnel, J.Chem.Phys., Vol.27, (1957) pp226.
    http://geocities.com/saravamudhan1944/crsi_6nsc_iitk.html

15. a. Adriaensens, R.Rego, R.Carleer, B.Ottenbourgs, J.Gelan., *Solid State NMR Relaxometry Study of Phenolic Resins,* Polymer International, Vol.52, No.10, (2000), pp 1647-1652.
    b. http://www.iscpubs.com/articles/aln/n9910roy.pdf Application Note on "*NMR in Process Control*"; a publication of International Scientific Communication Incorporated, 30 Controls Drive, PO BOX No. 870, Shelton, CT 06484-0870 U.S.A.
16. A.Derome, As in Ref.6 above. Chapters 8,9 & 10.

17. A.Derome, As in Ref.6. above. Chapter 5. *Nuclear Overhauser effect*.

18. K.H.Hauser & H.R.Kalbitzer, As in Ref No.7 above.
    a. Chapter 1. Section 1.2.1 *Chemical Shift*
    b. Section 1.2.2 *Dipole-Dipole Coupling*
    c. Section 1.2.3 *Indirect Spin-Spin Coupling*
    d. S.F.Sagnowski, S.Aravamudhan and U.Haeberlen, *Wide line and High Resolution Proton magnetic Resonance in Single crystals of Malonic Acid,* Journal of Magnetic Resonance, Vol.28 (1977) pp 271-288. Take particular note of the results page 276 where the inferences from the Wide line NMR studies on the geometry of CH_2 group is discussed.

19. A.Carrington and A.D.McLachlan, As in Ref.1C. above. Chapter 4
    a. Section 4.2 *Chemical shift*
    b. Section 4.3 *Spin-Spin Coupling*

20. A.Derome, As in Ref. No.6 above. Chapter 10. *Spin Echoes and J Spectroscopy*

21. a. K.H.Hauser and H.R.Kalbitzer, As in Ref.No.7. above. Chapter 3. Section 3.5.1.*Pattern Recognition in Two Dimensional NMR Spectra.*
    b. C.J.Pouchert and J.Behnke, *The Aldrich Library of ^{13}C and ^{1}H (FT NMR) Spectra,* Aldrich Chemicals, Milwankee wl1992 4,300 pages. This catalogue of NMR spectra is a three volumes set containing 12,000 High Resolution NMR Spectra (300MHz proton and 75MHz ^{13}C FT NMR) arranged according to functionality. Book **Z23,103-7** and CD ROM **Z54,126-5**

22. Melinda Duer, Black Well Publishing Limited UK (2004) Paper back ISBN 1-4051-0914-9 price £29.99

23. G.A.Web, edited Annual Reports on NMR Spectroscopy, Vol.21 contains an article entitled "***Graphics Aided NMR***", Academic Press.

24. http://www.process-nmr.com/ An On Line Announcement of an NMR service facility calling for Users for a wide variety NMR spectrometers.

SUGGESTED READING

1. John E.Wertz, *Nuclear and Electronic Spin Magnetic Resonance,* Chemical Reviews, Vol.55, (1955) page 829-901

2. K.H.Hausser, *Elektronen-und Kernresonanz als Methode der Molekul Forschung,* Angewandte Chemie, Vol.68, No.23 (1956) pp 729-752; Kern Magnetische Resonanz KMR pp 737

3. http://www.cis.rit.edu/htbooks/nmr/ *The Basics of NMR* (Internet On Line Book) by Joseph P.Hornak

4. F.Verburugge: *An interesting Laboratory macroscopic Model to demonstrate "Magnetic Resonance Effect" of tipping of a spin under the influence of an alternating magnetic Field has been described. This model demonstrates the magnetic resonance phenomena on a macroscopic dimensions using a bar magnet in the place of a nuclear magnetic moment..* American Journal of Physics, Vol.21 (1953) pp 653.

5. H.Friebolin, *Basic One- and Two- Dimensional NMR Spectrosciopy,* VCH Publications(1993).

6. K.Mullen and P.S.Pregogin, Fourier Transform NMR Techniques, A Practical Approach. Academic Press, London-New York (1976).

7. M.D.Grand and R.K.Harris, Eds., *Encyclopedia of Magnetic Resonance,* Wiley, Chichester, (1996).

FIGURE & TABLE CAPTIONS

Figure-1. (a) Block Diagram of a Simple Continuous Wave NMR Spectrometer

(b) Block Diagram of a Pulsed Fourier Transform NMR Spectrometer

Figure-2. (a)-(d) Simulated ^{13}C Nuclear Magnetic Resonance Spectra with the Chemical Shift values Calculated using a PROGRAM (http://www.cosmos-software.de). This is typically how the NMR spectrum from a Spectrometer would look with Broad Band Decoupling at the Protons so that the spin-spin splittings due to the heteronuclear ^{13}C-H spin-spin interactions do not appear in the Carbon Spectrum.

Figure-3. An example of Two sets of protons in a molecular fragment. One set of lines (a quartet) integrates to two protons, and the other set (triplet) integrates to three protons. Total integration amplitude is 5. This is a typical appearance of a proton NMR spectrum. The above are here calculated plots using MS Excel Applications. This serves the purpose of only an introductory material to be able to be familiar when the actual NMR spectra obtained for samples placed in NMR Spectrometer are to be recognized. The two protons of the CH_2 (methylene) group (integrates to two) are split into four lines (quartet) indicating an interaction with three neighboring protons of the CH_3 (methyl) group. The methyl group protons are split into three lines (triplet) due to the 2 protons of the methylene group

Figure-4. (a) This is an illustration of NMR line as a function of time from the non-equilibrium situation of inverted NMR line, the trace at the extreme left. The exponential growth is obvious. This again has been calculated (and hence simulated for illustration) using MS Excel Application. The same equation as used for earlier case with an exponentially varying amplitude factor as multiplier (serially stacked for comparison of relative amplitudes).

(b) The above is the illustration of NMR line as a function of time from the non-equilibrium situation of inverted NMR line, the trace at extreme left. The exponential growth is obvious. This again has been calculated (and hence simulated for illustration) using MS Excel Application. The same equation as used for earlier case with an exponentially varying amplitude factor as multiplier. (A parallel stack plot depiction)

(c) Experimental results from an Inversion recovery Experiment on a Proton Sample. By pulsed methods initial population distributions can be prepared in such a way the populations in the energy levels at thermal equilibrium can be ineverted and hence a NMR signal with negative intensity is obtained. Then this signal is allowed to reach thermal equilibrium situation and periodically the growth is monitored. The group of peaks at lower field (i.e., to the left) all have slightly longer T_1's tan those of the high-field group.

Figure-5. (a) An explanation of the mechanism of Shielding that is measured as Chemical shifts in NMR.

(b) The above graph was made using the MS Excel Application Program and was run on MSWindow. Magnetic Field was swept symmetrically about a Center Value (assigned zero) but the actual experimental sweep variation would have to be **H_{center}±10** units.The equation used was:-

$$Intensity = (width/\sqrt{\pi}) \times [\{1/((width)^2 + (fieldvalue - resonance1)^2)\} +$$

$$\{1/((width)^2 + (fieldvalue - resonance2)^2)\}]$$

Thus the two resonance lies with values -4 and +4 as in the lowest trace have splitting of 8 units resulting in a separation larger than the width value assigned to be **2** units. For all the traces (5 of the above) the width was the same 2 units all through and the line separations changed from 8units, through 6,4 and 2 to 0 value for the top most. For each trace the maximum from the base line increases since the lines contribute more and more at the zero value. Note that both the well separated lines in the lowest trace have equal amplitude from the base line which is **0.26**. The top most trace where the splitting is zero, the two lines resonate at the same field zero and hence the amplitude is **0.52** twice that the individual lines in the lowest trace. The lowest trace would be said to be **“well resolved”** spectrum.

Figure-5. (c) Change of line shapes with the exchange correlation time τ_e. Simulation of two-site exchange as a function of $|\Delta\varpi\tau_e|$ with an equilibrium constant K depending on the probability at the two sites. (a) and using an equation by McConnel (b).

Figure-6. A Calculated (Using MS Excel) Ethanol Spectrum depicting the Moderate Resolution and High Resolution NMR features**.**

Figure-7. (a),(b) NMR Spectrum of PF_3. The corresponding Flourine NMR(a) and the Phosphorus NMR (b). **7(c).** Number (2NI+1) and intensities of resonance lines in case of coupling with N equivalent nuclei with spin I.

Figure-8. (a) Proton NMR Spectrum of 95% Ethanol recorded at 500 MHz with Integration. Reference compound is DSS. **(c) simulated A_2X_3** weak and strong Coupling in a two spin system. **(b)** NMR spectrum of Ethanol at different Spectrometer frequencies: from tiop to bottom; 3MHz, 6MHz, 15MHz, 30MHz and 60MHz.

Figure-9 (a) A low-field NMR spectrum of a sample to be compared with the **(b)** High Field 500MHz spectrum of the same sample. Demonstrates the simplicity arising from Higher Magnetic Field Strength.

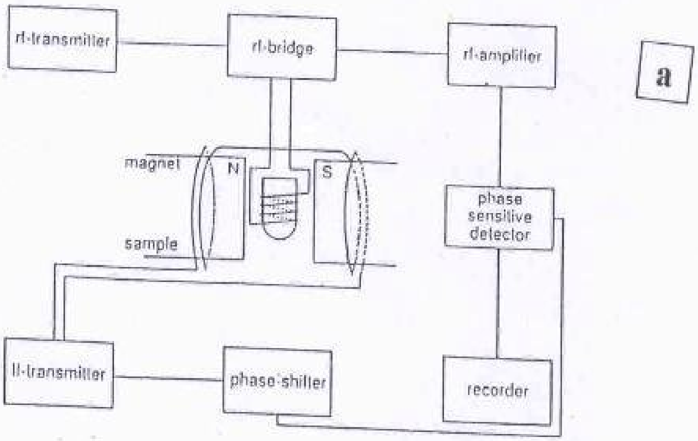
Figure-10. NMR Line positions of Aromatic ring protons for the different substitutions for the effects at Ortho, Meta and para positions. Further elaborations of these substitution effects can be found in the refernce: Speisecke and Schneider, *^{13}C And Proton Shifts In Substituted Benzenes*, J.Chem.Phys., 35, (1961) pp 731.

Table-1. Properties of Some Important nuclei.

Table-2. Commonly Used References in Biological NMR

Table-3. Chemical Shift assignments in Protein molecules.

Table-4. Chemical shift values with reference to benzene protons for different substitutions



(a) Block Diagram of a Simple Continuous Wave NMR Spectrometer

(b) Block Diagram of a Pulsed Fourier Transform NMR Spectrometer

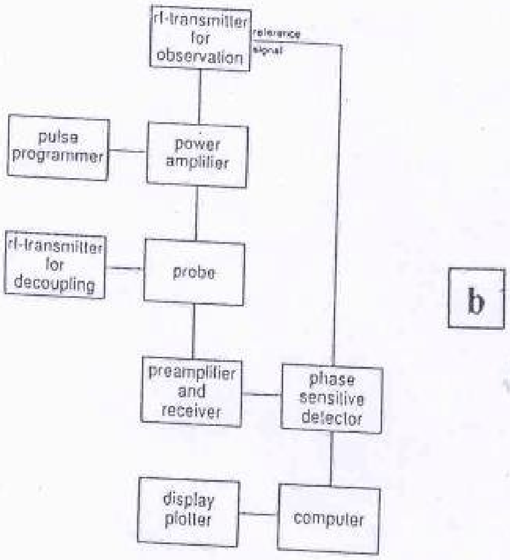
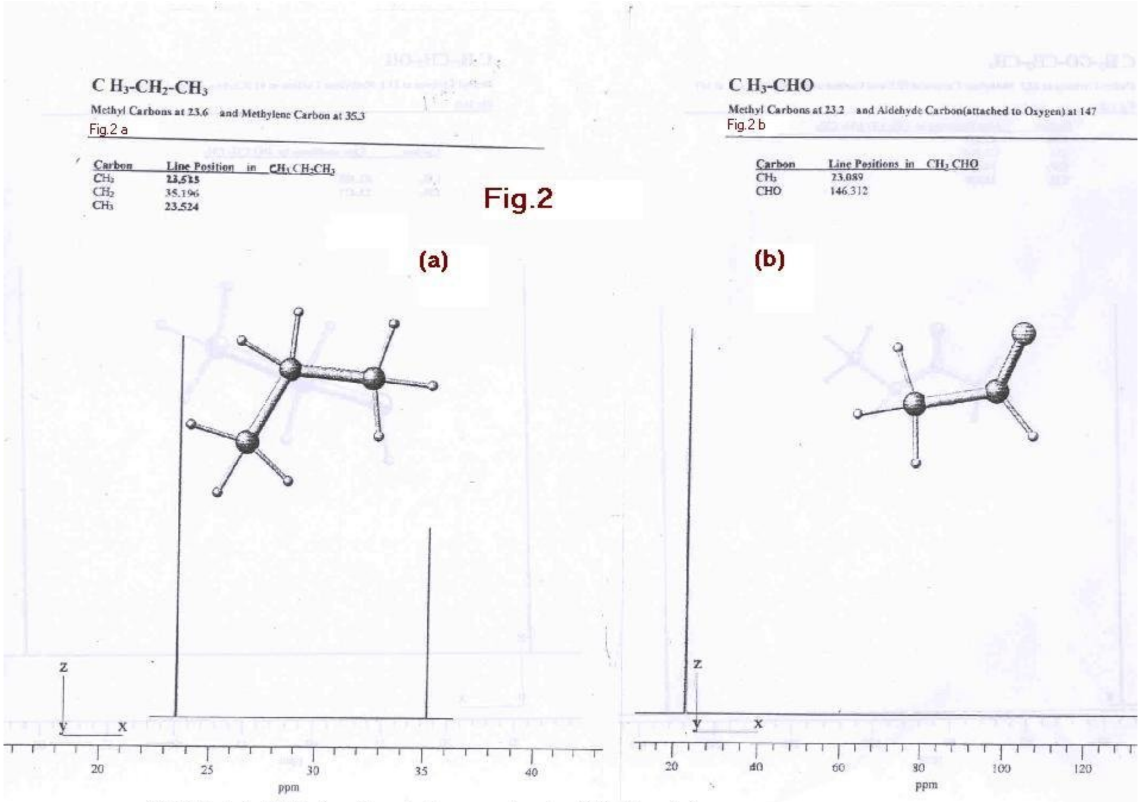


FIGURE -1



C H_3-CH_2-CH_3

Methyl Carbons at 23.6 and Methylene Carbon at 35.3

Fig.2 a

Carbon	Line Position in CH_3 $CH_2$$CH_3$
CH_3	23.515
CH_2	35.196
CH_3	23.524

C H_3-CHO

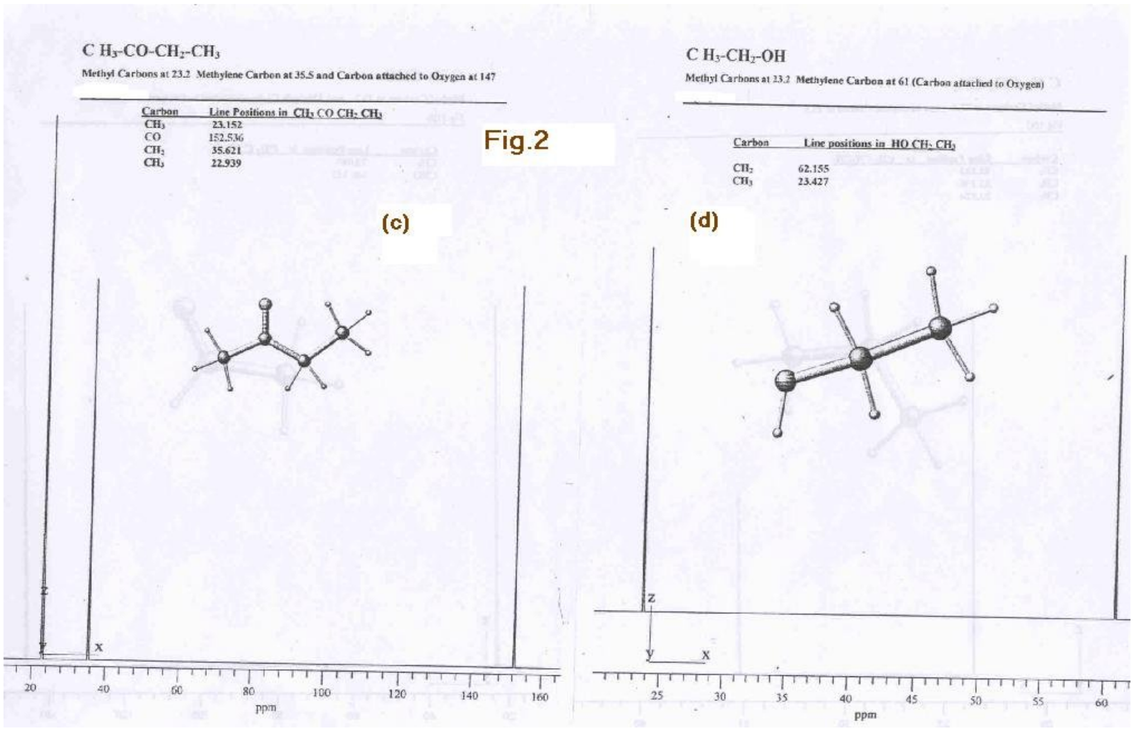
Methyl Carbons at 23.2 and Aldehyde Carbon(attached to Oxygen) at 147

Fig.2 b

Carbon	Line Positions in CH_3 CHO
CH_3	23.089
CHO	146.312

. (a)-(d) Simulated ^{13}C Nuclear Magnetic Resonance Spectra with the Chemical Shift values Calculated using a PROGRAM (http://www.cosmos-software.de). This is typically how the NMR spectrum from a Spectrometer would look with Broad Band Decoupling at the Protons so that the spin-spin splittings due to the heteronuclear ^{13}C-H spin-spin interactions do not appear in the Carbon Spectrum.

c and d are on another page



C H_3-CO-CH_2-CH_3

Methyl Carbons at 23.2 Methylene Carbon at 35.5 and Carbon attached to Oxygen at 147

Carbon	Line Positions in CH_3 CO CH_2 CH_3
CH_3	23.152
CO	152.536
CH_2	35.621
CH_3	22.939

C H_3-CH_2-OH

Methyl Carbons at 23.2 Methylene Carbon at 61 (Carbon attached to Oxygen)

Carbon	Line positions in HO CH_2 CH_3
CH_2	62.155
CH_3	23.427

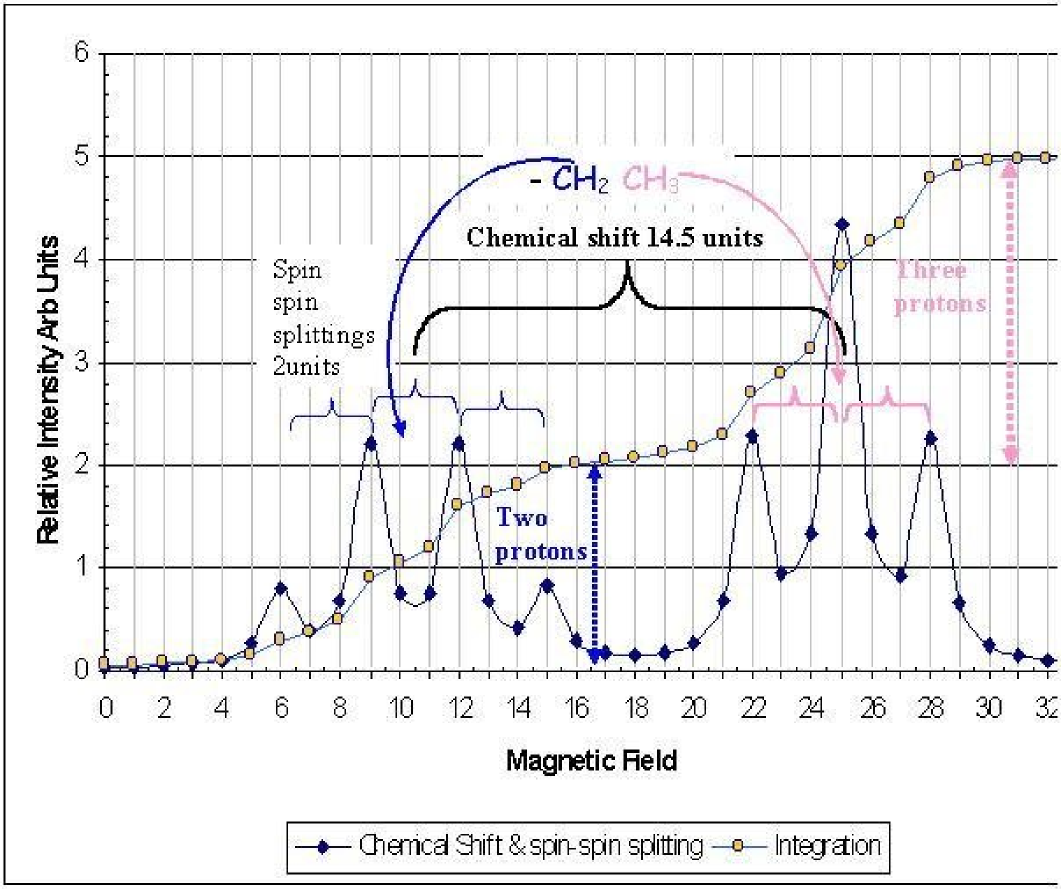


FIGURE-3

An example of Two sets of protons in a molecular fragment. One set of lines (a quartet) integrates to two protons, and the other set (triplet) integrates to three protons. Total integration amplitude is 5. This is a typical appearance of a proton NMR spectrum. The above are here calculated plots using MS Excel Applications. This serves the purpose of only an introductory material to be able to be familiar when the actual NMR spectra obtained for samples placed in NMR Spectrometer are to be recognized. The two protons of the CH_2 (methylene) group (integrates to two) are split into four lines (quartet) indicating an interaction with three neighboring protons of the CH_3 (methyl) group. The methyl group protons are split into three lines (triplet) due to the 2 protons of the methylene group

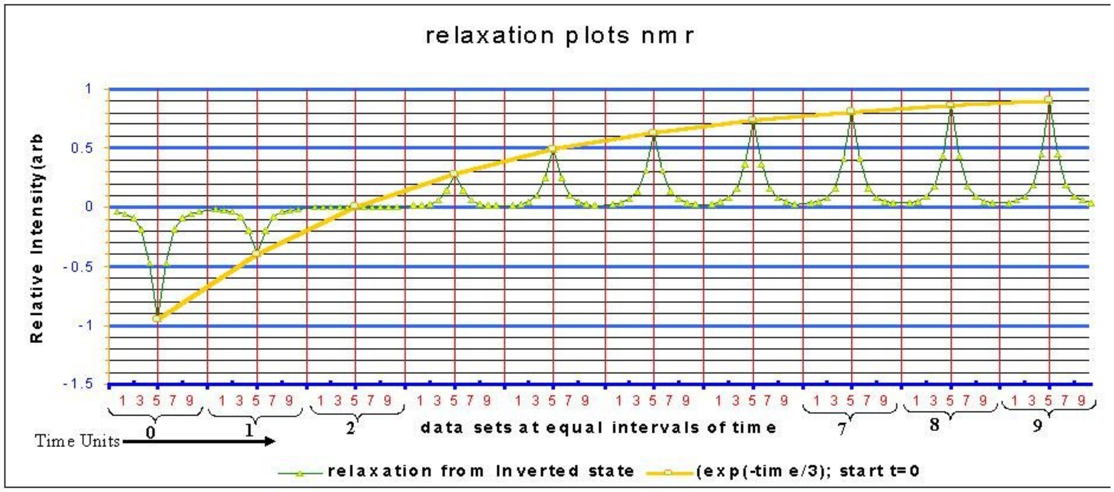


FIGURE – 4 (a)

This is an illustration of NMR line as a function of time from the non-equilibrium situation of inverted NMR line, the trace at the extreme left. The exponential growth is obvious. This again has been calculated (and hence simulated for illustration) using MS Excel Application. The same equation as used for earlier case with an exponentially varying amplitude factor as multiplier (serially stacked for comparison of relative amplitudes).

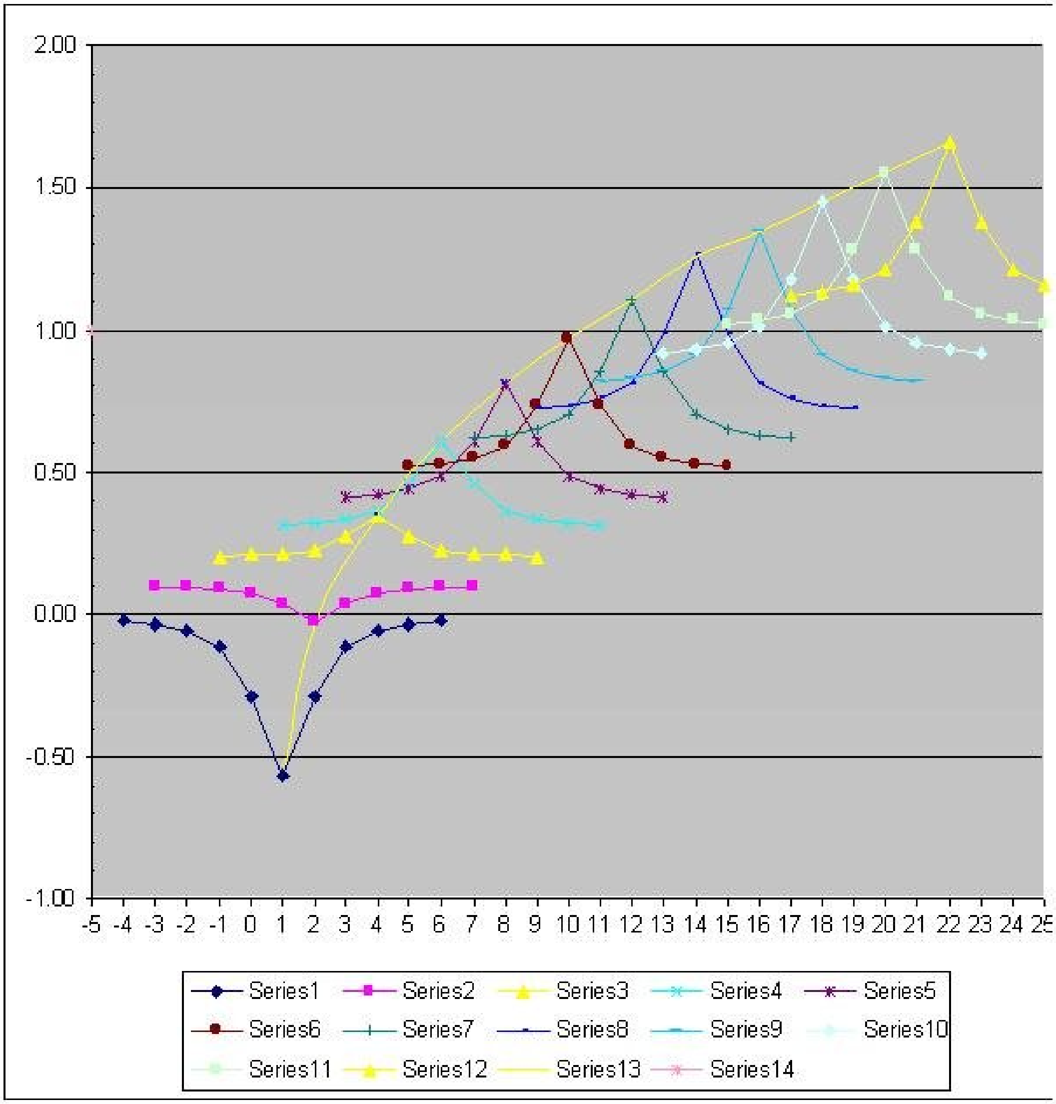
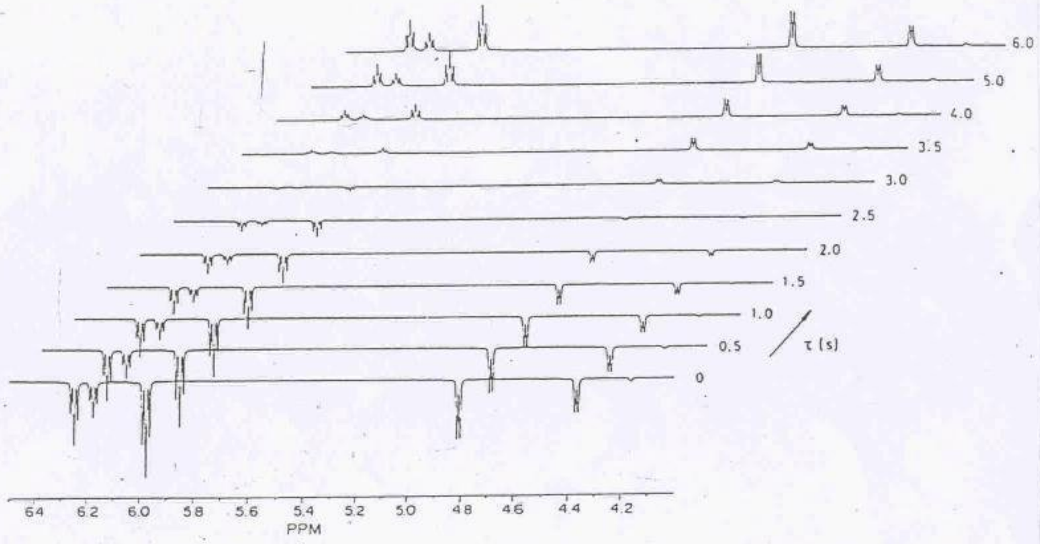


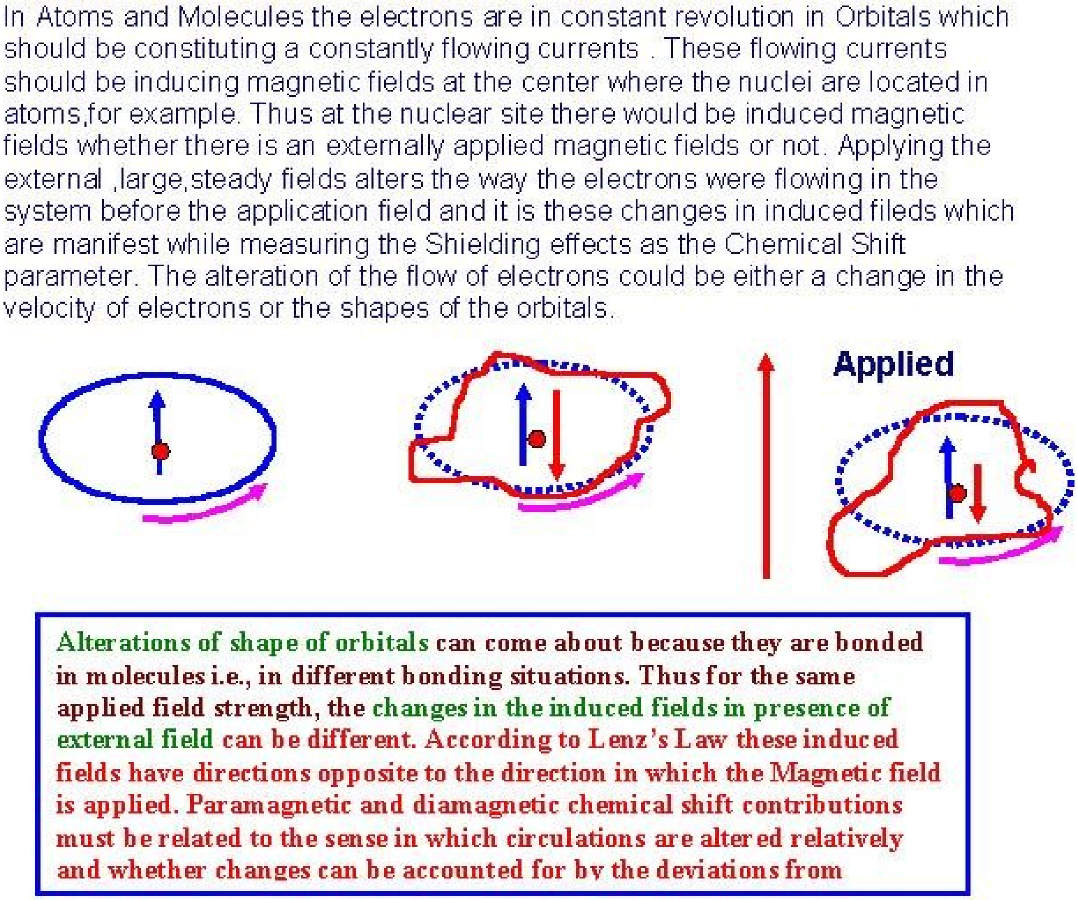
FIGURE-4(b)

The above is the illustration of NMR line as a function of time from the non-equilibrium situation of inverted NMR line, the trace at extreme left. The exponential growth is obvious. This again has been calculated (and hence simulated for illustration) using MS Excel Application. The same equation as used for earlier case with an exponentially varying amplitude factor as multiplier. (A parallel stack plot depiction)

Experimental results from an Inversion recovery Experiment on a Proton Sample. By pulsed methods initial population distributions can be prepared in such a way the populations in the energy levels at thermal equilibrium can be ineverted and hence a NMR signal with negative intensity is obtained. Then this signal is allowed to reach thermal equilibrium situation and periodically the growth is monitored. The group of peaks at lower field (i.e., to the left) all have slightly longer T_1's tan those of the high-field group.

FIGURE-4 **c**





In Atoms and Molecules the electrons are in constant revolution in Orbitals which should be constituting a constantly flowing currents . These flowing currents should be inducing magnetic fields at the center where the nuclei are located in atoms,for example. Thus at the nuclear site there would be induced magnetic fields whether there is an externally applied magnetic fields or not. Applying the external ,large,steady fields alters the way the electrons were flowing in the system before the application field and it is these changes in induced fileds which are manifest while measuring the Shielding effects as the Chemical Shift parameter. The alteration of the flow of electrons could be either a change in the velocity of electrons or the shapes of the orbitals.

Alterations of shape of orbitals can come about because they are bonded in molecules i.e., in different bonding situations. Thus for the same applied field strength, the changes in the induced fields in presence of external field can be different. According to Lenz's Law these induced fields have directions opposite to the direction in which the Magnetic field is applied. Paramagnetic and diamagnetic chemical shift contributions must be related to the sense in which circulations are altered relatively and whether changes can be accounted for by the deviations from

FIGURE-5(a)

. **(a)** An explanation of the mechanism of Shielding that is measured as Chemical shifts in NMR.

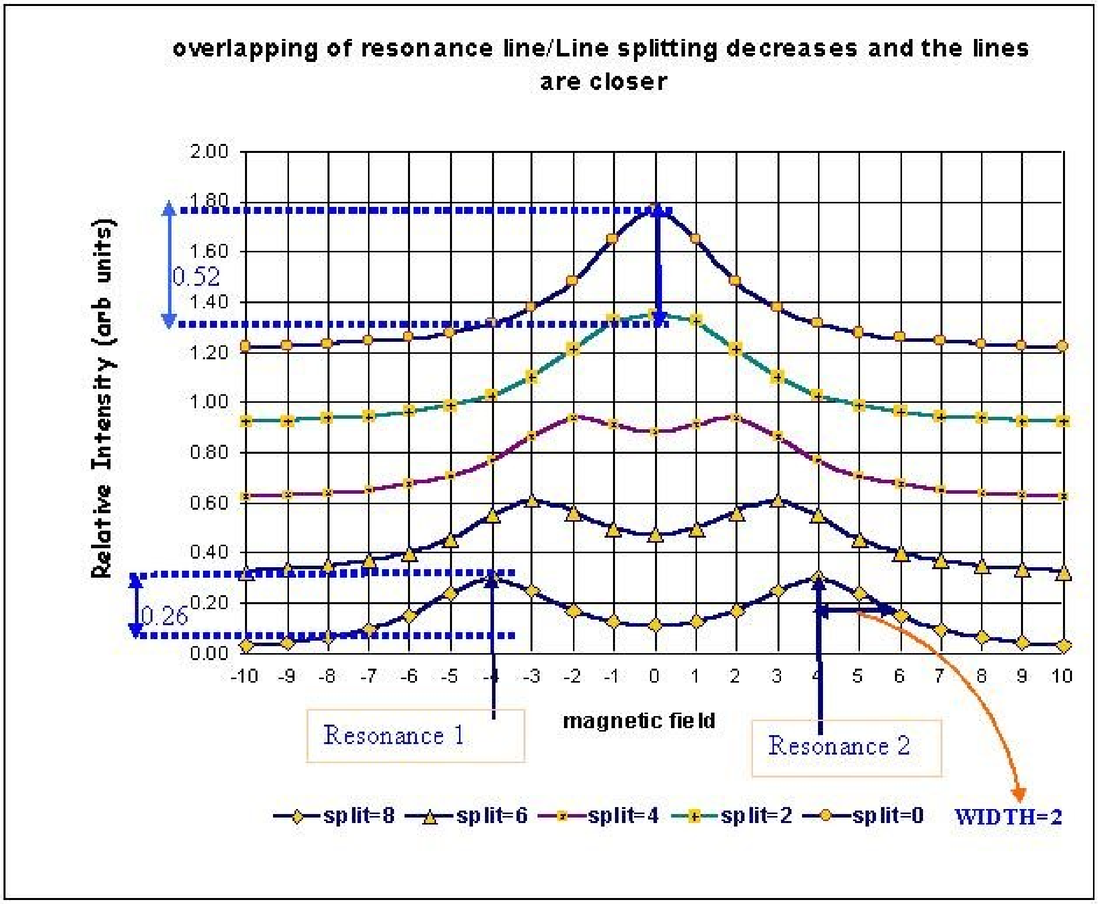


FIGURE-5(b)

The above graph was made using the MS Excel Application Program and was run on MSWindow. Magnetic Field was swept symmetrically about a Center Value (assigned zero) but the actual experimental sweep variation would have to be **H_{center}±10** units.The equation used was:-

$$Intensity = (width/\sqrt{\pi}) \times [\{1/((width)^2 + (fieldvalue - resonance1)^2)\} + \{1/((width)^2 + (fieldvalue - resonance2)^2)\}]$$

Thus the two resonance lies with values -4 and +4 as in the lowest trace have splitting of 8 units resulting in a separation larger than the width value assigned to be **2** units. For all the traces (5 of the above) the width was the same 2 units all through and the line separations changed from 8units, through 6,4 and 2 to 0 value for the top most. For each trace the maximum from the base line increases since the lines contribute more and more at the zero value. Note that both the well separated lines in the lowest trace have equal amplitude from the base line which is **0.26**. The top most trace where the splitting is zero, the two lines resonate at the same field zero and hence the amplitude is **0.52** twice that the individual lines in the lowest trace. The lowest trace would be said to be **"well resolved"** spectrum.

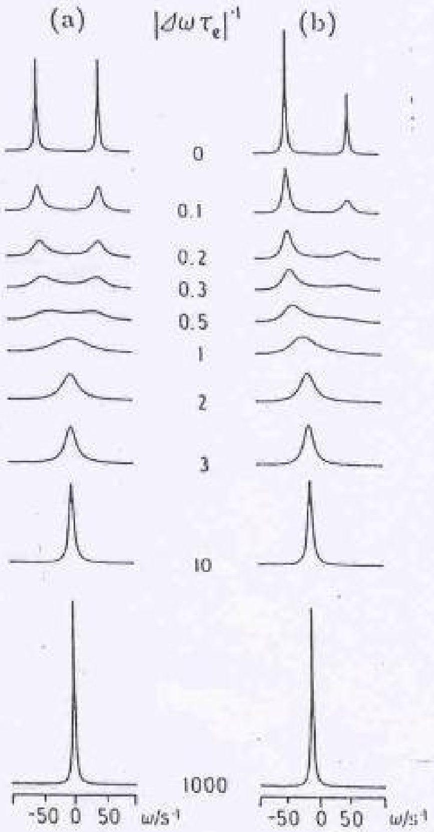


FIGURE-5

c

Change of line shapes with the exchange correlation time τ_e. Simulation of two- site exchange as a function of $|\Delta\omega\tau_e|$ with an equilibrium constant K depending on the probability at the two sites. (a) and using an equation by McConnel (b).

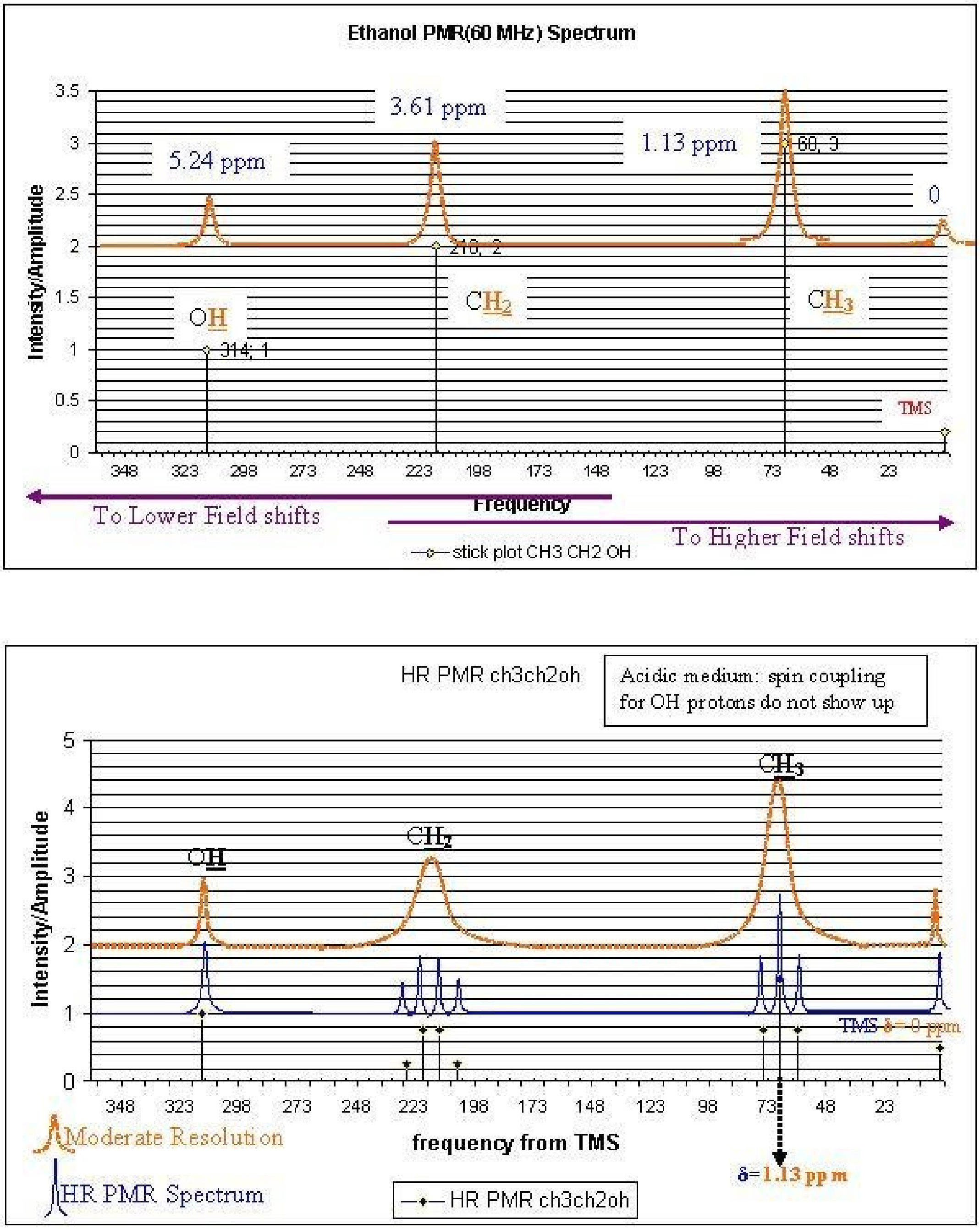
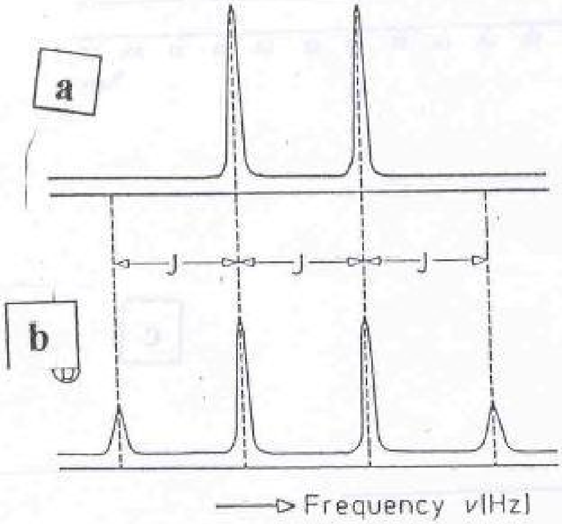
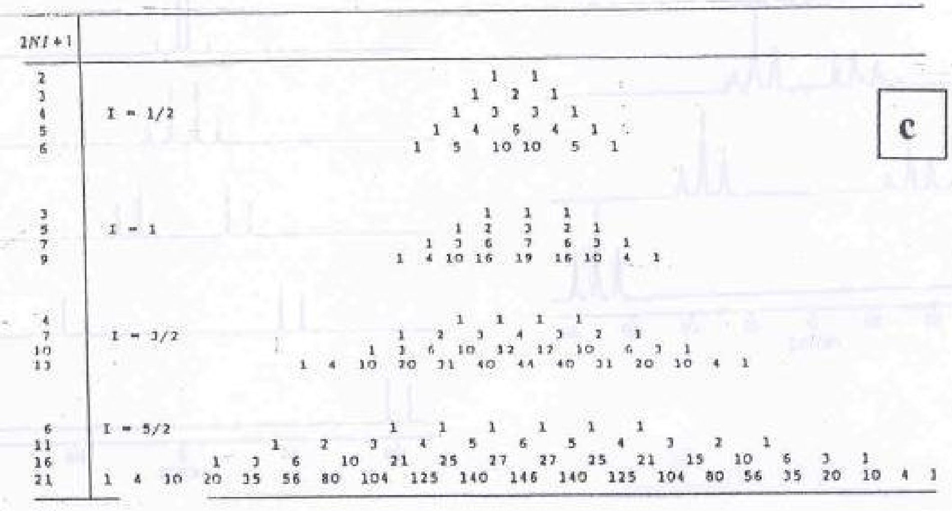


FIGURE 6

A Calculated (Using MS Excel) Ethanol Spectrum depicting the Moderate Resolution and High Resolution NMR features.

Figure-7. (a),(b) NMR Spectrum of PF_3. The corresponding Flourine NMR(a) and the Phosphorus NMR (b). **7(c).** Number (2NI+1) and intensities of resonance lines in case of coupling with N equivalent nuclei with spin I.





2NI+1		
2	I = 1/2	1 1
3		1 2 1
4		1 3 3 1
5		1 4 6 4 1
6		1 5 10 10 5 1
3	I = 1	1 1 1
5		1 2 3 2 1
7		1 3 6 7 6 3 1
9		1 4 10 16 19 16 10 4 1
4	I = 3/2	1 1 1 1
7		1 2 3 4 3 2 1
10		1 3 6 10 12 12 10 6 3 1
13		1 4 10 20 31 40 44 40 31 20 10 4 1
6	I = 5/2	1 1 1 1 1 1
11		1 2 3 4 5 6 5 4 3 2 1
16		1 3 6 10 21 25 27 27 25 21 15 10 6 3 1
21		1 4 10 20 35 56 80 104 125 140 146 140 125 104 80 56 35 20 10 4 1

FIGURE-7

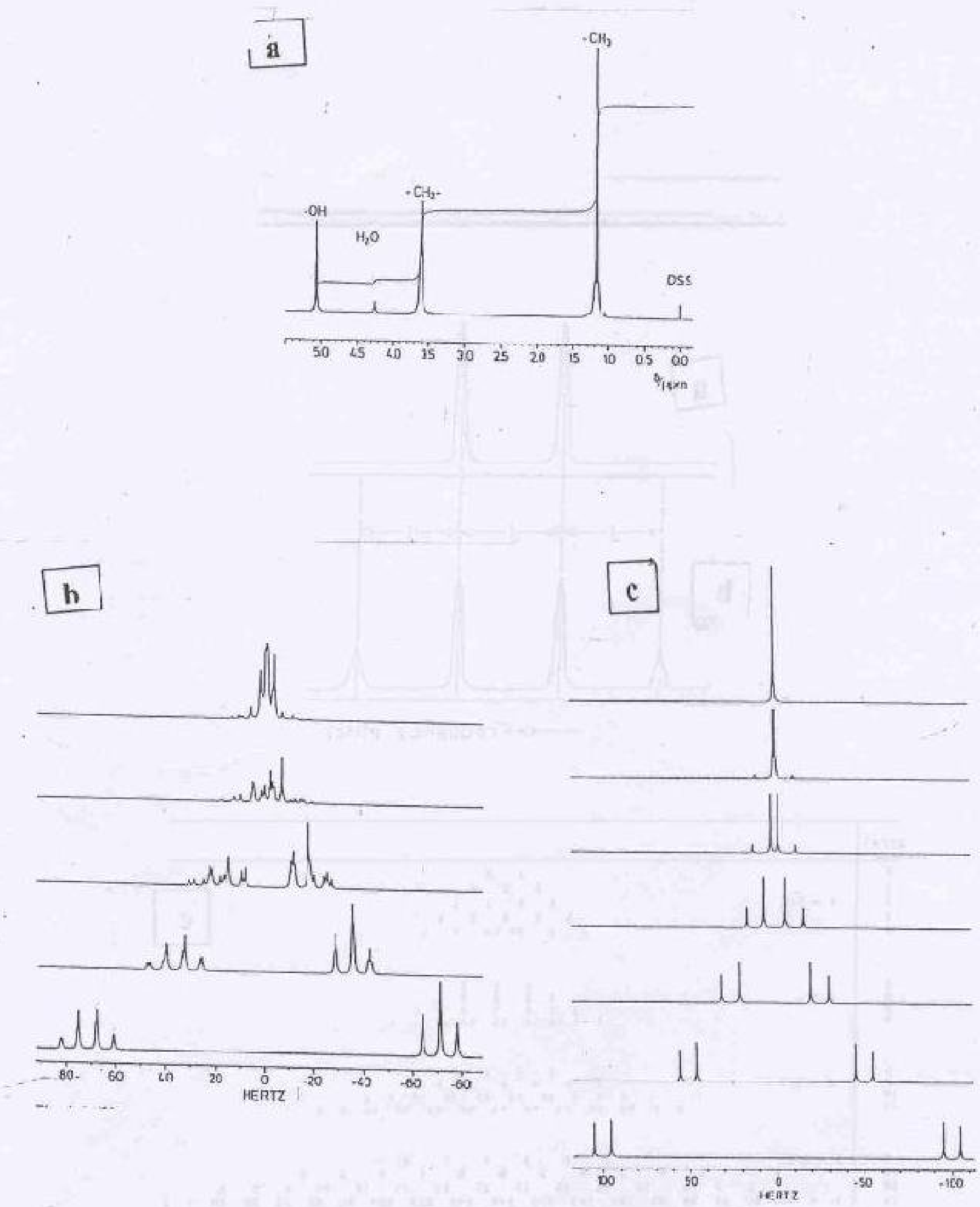


FIGURE-8

. **(a)** Proton NMR Spectrum of 95% Ethanol recorded at 500 MHz with Integration. Reference compound is DSS. **(c) simulated A_2X_3** weak and strong Coupling in a two spin system. **(b)** NMR spectrum of Ethanol at different Spectrometer frequencies: from tiop to bottom; 3MHz, 6MHz, 15MHz, 30MHz and 60MHz.

(a) A low-field NMR spectrum of a sample to be compared with the **(b)** High Field 500MHz spectrum of the same sample. Demonstrates the simplicity arising from Higher Magnetic Field Strength.

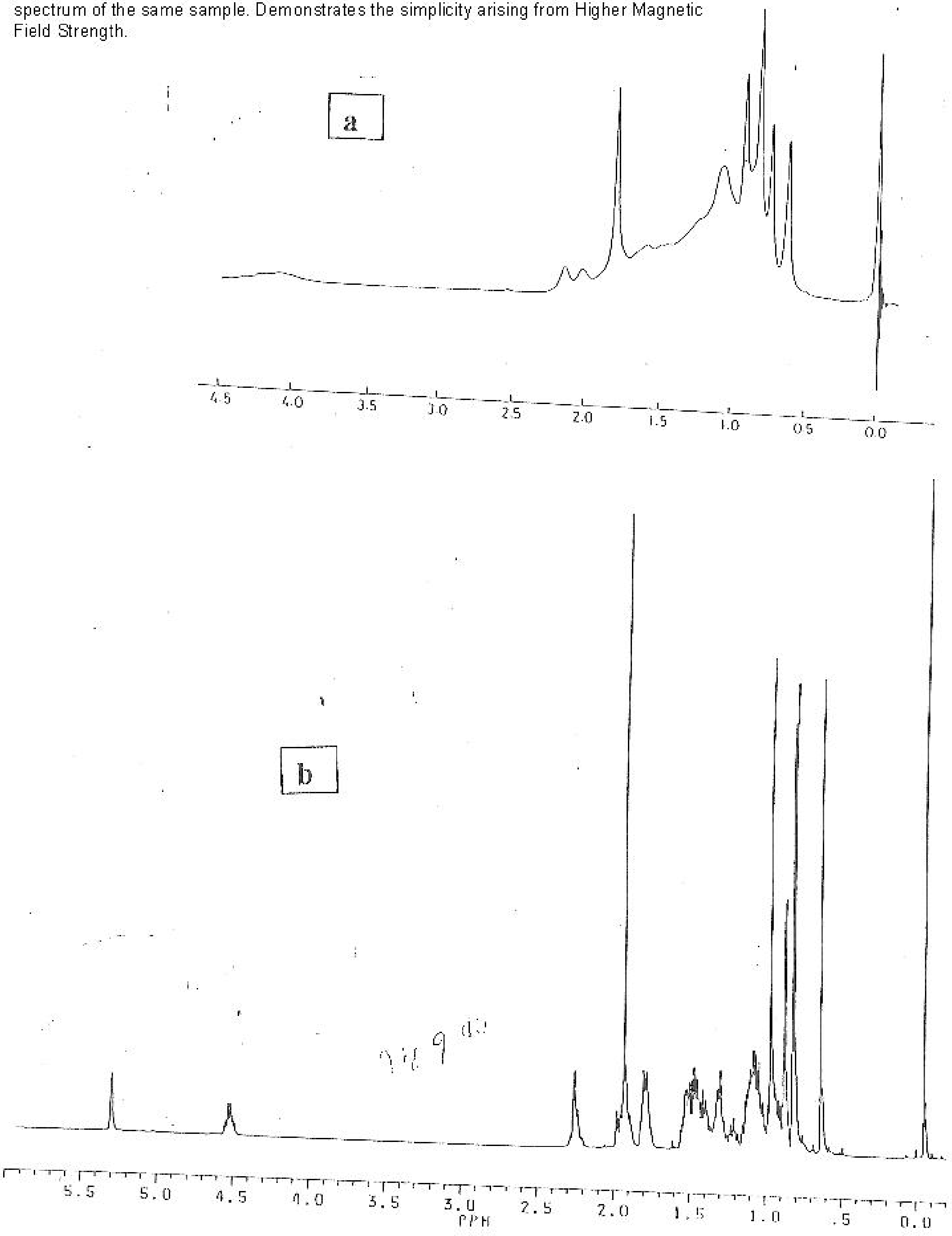


FIGURE-9

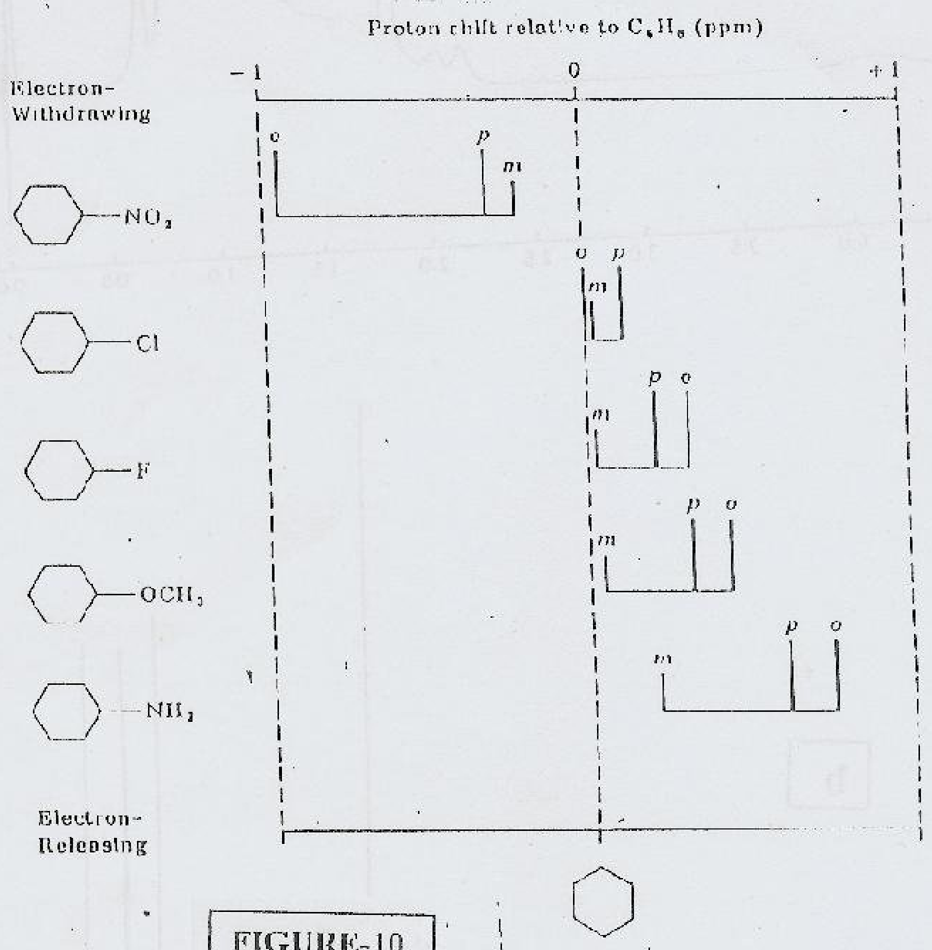
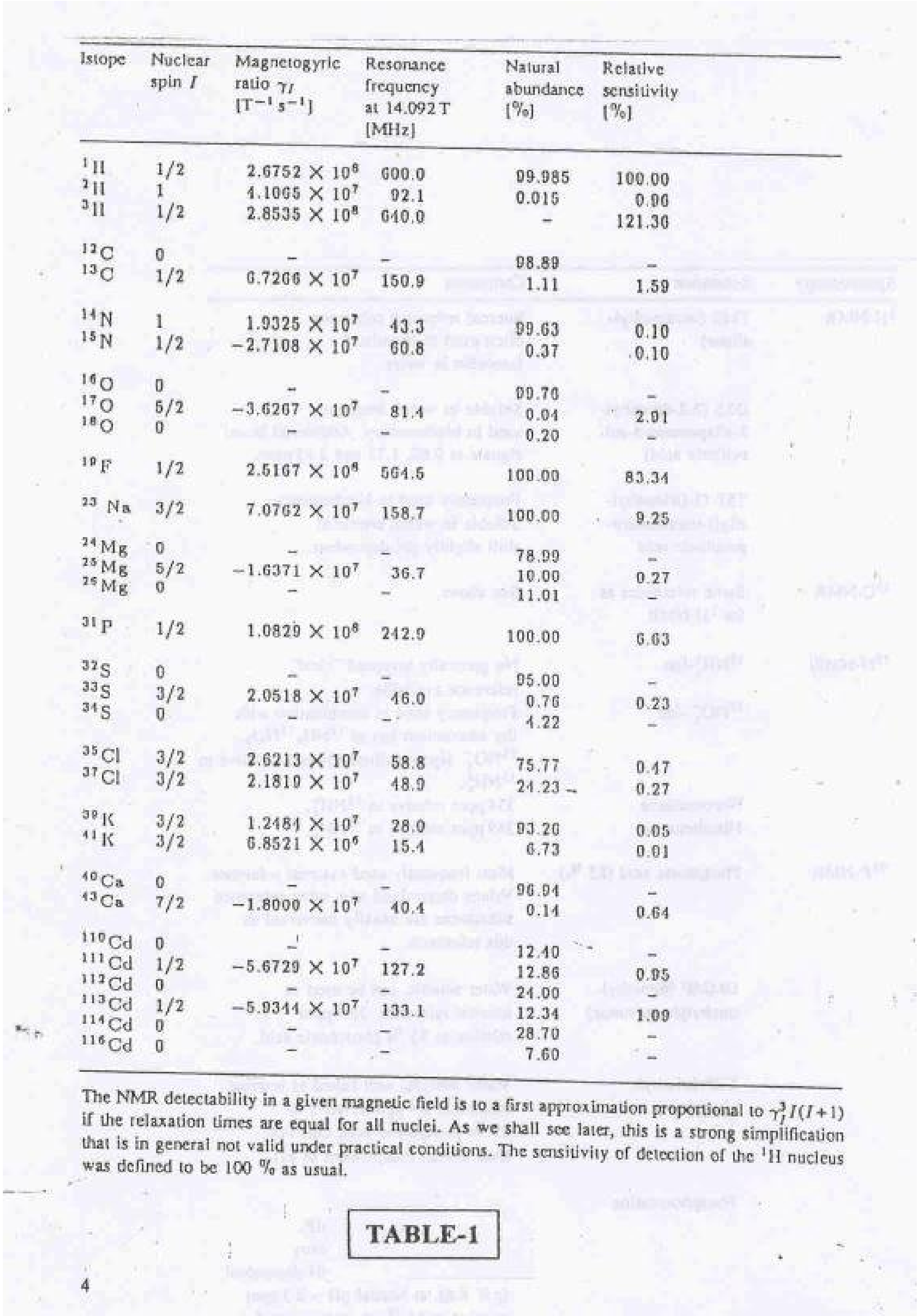


FIGURE-10

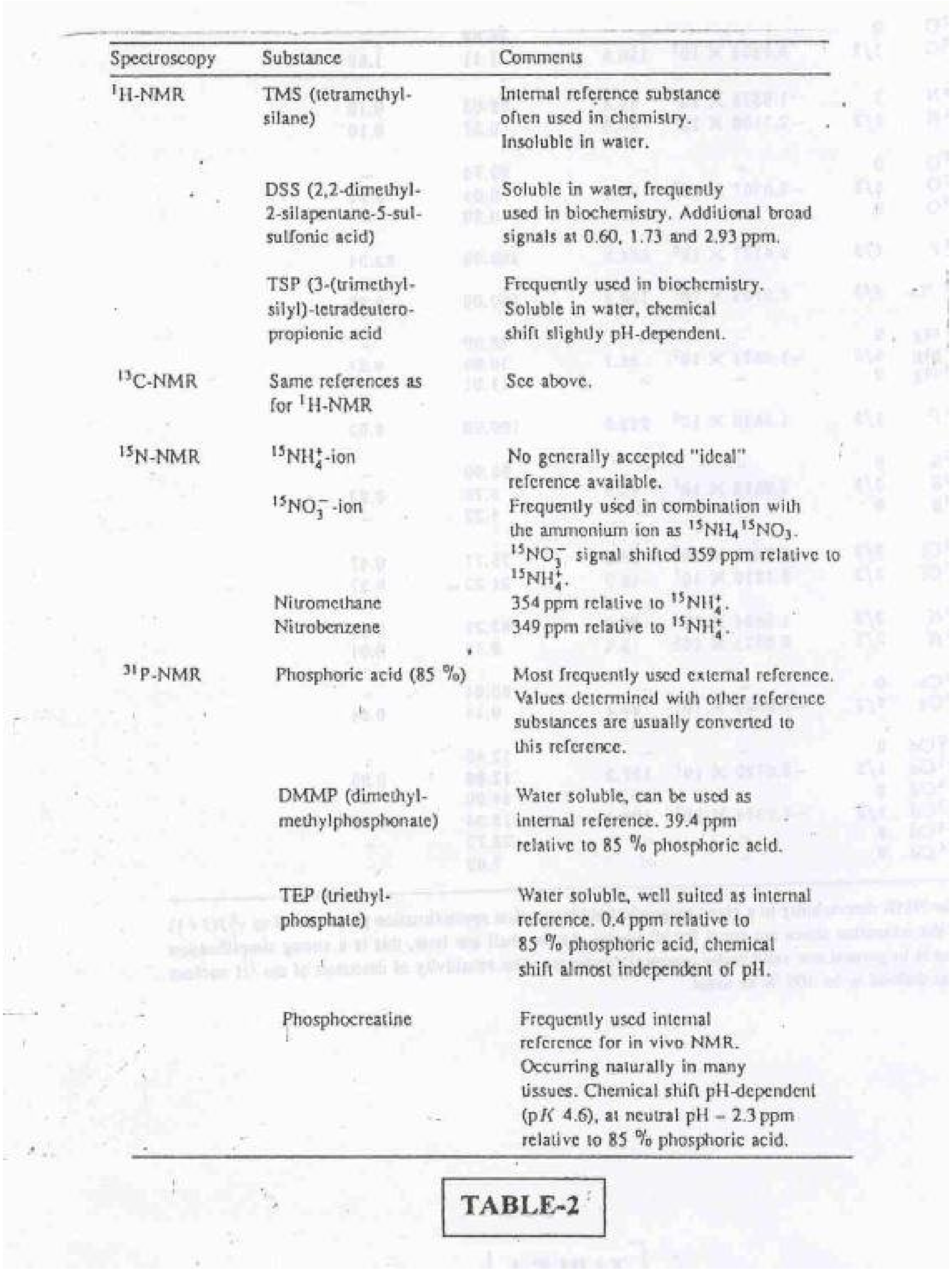
NMR Line positions of Aromatic ring protons for the different substitutions for the effects at Ortho, Meta and para positions. Further elaborations of these substitution effects can be found in the refernce: Speisecke and Schneider, ^{13}*C And Proton Shifts In Substituted Benzenes*, J.Chem.Phys., 35, (1961) pp 731.



Istope	Nuclear spin I	Magnetogyric ratio γ_I $[T^{-1} s^{-1}]$	Resonance frequency at 14.092 T [MHz]	Natural abundance [%]	Relative sensitivity [%]
^{1}H	1/2	2.6752×10^{8}	600.0	99.985	100.00
^{2}H	1	4.1065×10^{7}	92.1	0.015	0.96
^{3}H	1/2	2.8535×10^{8}	640.0	–	121.30
^{12}C	0	–	–	98.89	–
^{13}C	1/2	6.7266×10^{7}	150.9	1.11	1.59
^{14}N	1	1.9325×10^{7}	43.3	99.63	0.10
^{15}N	1/2	-2.7108×10^{7}	60.8	0.37	0.10
^{16}O	0	–	–	99.76	–
^{17}O	5/2	-3.6267×10^{7}	81.4	0.04	2.91
^{18}O	0	–	–	0.20	–
^{19}F	1/2	2.5167×10^{8}	564.5	100.00	83.34
^{23}Na	3/2	7.0762×10^{7}	158.7	100.00	9.25
^{24}Mg	0	–	–	78.99	–
^{25}Mg	5/2	-1.6371×10^{7}	36.7	10.00	0.27
^{26}Mg	0	–	–	11.01	–
^{31}P	1/2	1.0829×10^{8}	242.9	100.00	6.63
^{32}S	0	–	–	95.00	–
^{33}S	3/2	2.0518×10^{7}	46.0	0.76	0.23
^{34}S	0	–	–	4.22	–
^{35}Cl	3/2	2.6213×10^{7}	58.8	75.77	0.47
^{37}Cl	3/2	2.1819×10^{7}	48.9	24.23	0.27
^{39}K	3/2	1.2484×10^{7}	28.0	93.20	0.05
^{41}K	3/2	6.8521×10^{6}	15.4	6.73	0.01
^{40}Ca	0	–	–	96.94	–
^{43}Ca	7/2	-1.8000×10^{7}	40.4	0.14	0.64
^{110}Cd	0	–	–	12.40	–
^{111}Cd	1/2	-5.6729×10^{7}	127.2	12.86	0.95
^{112}Cd	0	–	–	24.00	–
^{113}Cd	1/2	-5.9344×10^{7}	133.1	12.34	1.09
^{114}Cd	0	–	–	28.70	–
^{116}Cd	0	–	–	7.60	–

The NMR detectability in a given magnetic field is to a first approximation proportional to $\gamma_I^3 I(I+1)$ if the relaxation times are equal for all nuclei. As we shall see later, this is a strong simplification that is in general not valid under practical conditions. The sensitivity of detection of the ^{1}H nucleus was defined to be 100 % as usual.

TABLE-1



Spectroscopy	Substance	Comments
^{1}H-NMR	TMS (tetramethylsilane)	Internal reference substance often used in chemistry. Insoluble in water.
	DSS (2,2-dimethyl-2-silapentane-5-sulsulfonic acid)	Soluble in water, frequently used in biochemistry. Additional broad signals at 0.60, 1.73 and 2.93 ppm.
	TSP (3-(trimethylsilyl)-tetradeuteropropionic acid	Frequently used in biochemistry. Soluble in water, chemical shift slightly pH-dependent.
^{13}C-NMR	Same references as for ^{1}H-NMR	See above.
^{15}N-NMR	$^{15}NH_4^+$-ion	No generally accepted "ideal" reference available.
	$^{15}NO_3^-$-ion	Frequently used in combination with the ammonium ion as $^{15}NH_4{}^{15}NO_3$. $^{15}NO_3^-$ signal shifted 359 ppm relative to $^{15}NH_4^+$.
	Nitromethane	354 ppm relative to $^{15}NH_4^+$.
	Nitrobenzene	349 ppm relative to $^{15}NH_4^+$.
^{31}P-NMR	Phosphoric acid (85 %)	Most frequently used external reference. Values determined with other reference substances are usually converted to this reference.
	DMMP (dimethylmethylphosphonate)	Water soluble, can be used as internal reference. 39.4 ppm relative to 85 % phosphoric acid.
	TEP (triethylphosphate)	Water soluble, well suited as internal reference. 0.4 ppm relative to 85 % phosphoric acid, chemical shift almost independent of pH.
	Phosphocreatine	Frequently used internal reference for in vivo NMR. Occurring naturally in many tissues. Chemical shift pH-dependent (pK 4.6), at neutral pH − 2.3 ppm relative to 85 % phosphoric acid.

TABLE-2

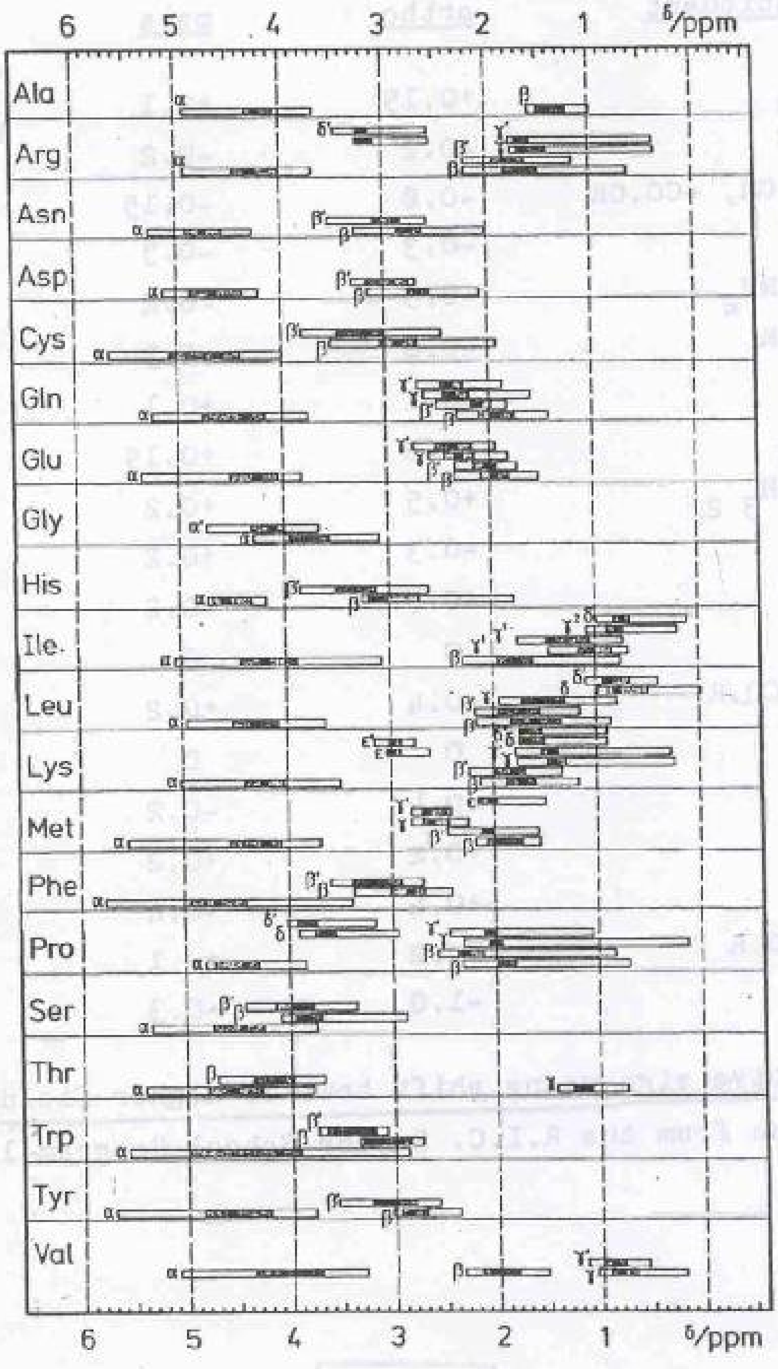

6
5
4
3
2
1
δ/ppm
Ala
Arg
Asn
Asp
Cys
Gln
Glu
Gly
His
Ile
Leu
Lys
Met
Phe
Pro
Ser
Thr
Trp
Tyr
Val
α
β
β'
γ
γ'
δ
δ'
ε
ε'
α'

TABLE-3

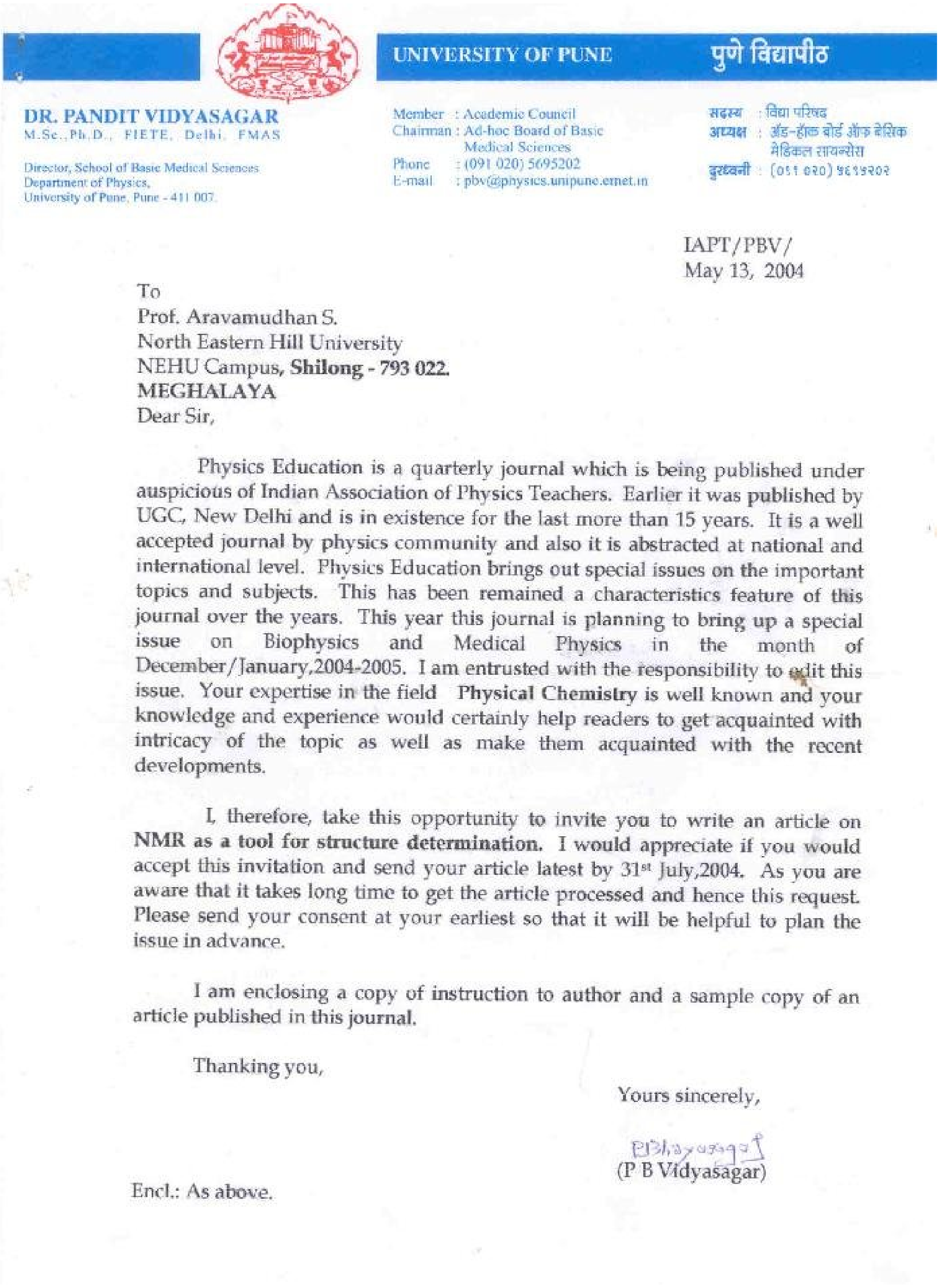
(Approx.) Shifts in the position of benzene protons ($\delta = 7.27$) caused by substituents

Substituent	ortho	meta	para
$-CH_3$	+0.15	+0.1	+0.1
$-C=C$	-0.2	-0.2	-0.2
$-CO.OH$, $-CO.OR$	-0.8	-0.15	-0.2
$-CN$	-0.3	-0.3	-0.3
$-CO.NH_2$	-0.5	-0.2	-0.2
$-CO.R$	-0.6	-0.3	-0.3
$-SR$	-0.1	+0.1	+0.2
$-NH_2$	+0.8	+0.15	+0.4
$-N(CH_3)_2$	+0.5	+0.2	+0.5
$-I$	-0.3	+0.2	+0.1
$-CHO$	-0.7	-0.2	-0.4
$-Br$	0	0	0
$-NH.CO.R$	-0.4	+0.2	+0.3
$-Cl$	0	0	0
$-NH_3^+$	-0.4	-0.2	-0.2
$-OR$	+0.2	+0.2	+0.2
$-OH$	+0.4	+0.4	+0.4
$-O.CO.R$	-0.2	+0.1	+0.2
$-NO_2$	-1.0	-0.3	-0.4

positive sign means shift towards higher field

(taken from the R.I.C. Summer School Program 1964)

TABLE-4



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दुरध्वनी : (०९१ ०२०) ५६९५२०२

IAPT/PBV/
May 13, 2004

To
Prof. Aravamudhan S.
North Eastern Hill University
NEHU Campus, **Shilong - 793 022.**
MEGHALAYA

Dear Sir,

Physics Education is a quarterly journal which is being published under auspicious of Indian Association of Physics Teachers. Earlier it was published by UGC, New Delhi and is in existence for the last more than 15 years. It is a well accepted journal by physics community and also it is abstracted at national and international level. Physics Education brings out special issues on the important topics and subjects. This has been remained a characteristics feature of this journal over the years. This year this journal is planning to bring up a special issue on Biophysics and Medical Physics in the month of December/January,2004-2005. I am entrusted with the responsibility to edit this issue. Your expertise in the field **Physical Chemistry** is well known and your knowledge and experience would certainly help readers to get acquainted with intricacy of the topic as well as make them acquainted with the recent developments.

I, therefore, take this opportunity to invite you to write an article on **NMR as a tool for structure determination.** I would appreciate if you would accept this invitation and send your article latest by 31st July,2004. As you are aware that it takes long time to get the article processed and hence this request. Please send your consent at your earliest so that it will be helpful to plan the issue in advance.

I am enclosing a copy of instruction to author and a sample copy of an article published in this journal.

Thanking you,

Yours sincerely,

(P B Vidyasagar)

Encl.: As above.