Modern Methods of Pharmaceutical Analysis

Volume II

Editor

Roger E. Schirmer

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FOREWORD

The analysis of pharmaceuticals can be subdivided into several distinct classes of analytical problems. The classes are listed in Table 1. Each class of problems imposes a unique set of constraints on the analyst. For example, the determination of the purity of a drug substance usually requires an analysis of high specificity and precision, but does not require high sensitivity or preliminary isolation of the analyte from a sample matrix. Analysis of a potent drug in a low dose formulation on the other hand requires selectivity, precision, high sensitivity, and (usually) a preliminary separation of the drug from excipients. Evaluation of reference standards requires use of absolute methods such as coulometry, differential scanning calorimetry, or NMR that do not need a standard of the test substance for calibration, and so on. As a consequence of the diverse requirements of the different classes of problems, all common organic analytical techniques are routinely used in pharmaceutical analysis. Instrumental methods are particularly important in modern pharmaceutical analysis, but classical procedures are often used in conjunction with them. The classical methods remain very important in routine quality control of pharmaceuticals.

The objective of "Modern Methods of Pharmaceutical Analysis" is to review the major methods in current use in pharmaceutical analysis. The review covers principles, special instrumentation, experimental techniques, and a survey of pharmaceutical applications for each method. The discussion of principles is intended to provide insight into important experimental variables, possible sources of error in applications of the technique, and factors that should be taken into account when adapting the method to solve new analytical problems. Tables of buffer compositions, characteristics of chromatographic column packings, physical properties of solvents, positions of UV, IR, and NMR absorption bands, and other frequently used reference data are also included in the text. The literature surveyed in each section has been selected to demonstrate the range of applications of the technique in pharmaceutical analysis and to provide essential details of specific applications that can serve as a guide in related analytical development efforts. More comprehensive reviews of the applications literature are referenced whenever they are available.

Table 1 Classes of Problems in Pharmaceutical Analysis

- Detection, isolation, and identification of impurities in a drug substance or formulation
- Evaluation of the purity of reference standards of drug substances -
- Purity determination of a drug substance for routine quality control
- Identification tests for quality control of a drug substance
- Determination of the potency of a formulation for routine quality control
- Identification of the drug substances in a formulation for routine quality control
- Evaluation of content uniformity for low dose formulations
- Analysis of other materials such as moisture, residual solvents, heavy metals, preservatives, specific impurities, etc. in drug substances and their formulations
- Determination of the chemical and physical stability of drug substances and their formulations
- Measurement of physical properties such as crystalline form, dissolution rate, disintegration times, hardness, pH, color, etc. for drug substances and formulations

INTRODUCTION

During the development of a new drug product, detailed chemical studies must be made of raw materials, synthetic intermediates, the drug substance itself, and the final formulated product. These studies must identify types and levels of impurities, degradation products, degradation rates, and analytical methods suitable for monitoring these factors. The information resulting from these studies is used to identify potential sources of safety problems in the product, to meet the requirements of foreign and domestic regulatory agencies, and as a basis for establishing quality control procedures and specifications for the product. The analytical effort required to provide this information can be divided into a number of tasks as shown in Table 1. The requirements for specificity, precision, accuracy, and the degree of complexity acceptable in the analytical procedure vary considerably from task to task and therefore require a variety of analytical techniques to satisfy them.

For example, the identification of impurities and degradation products requires the extensive use of chemical separations followed by qualitative analysis of the isolated product. Gas chromatography(GC) and high pressure liquid chromatography (HPLC) are frequently used to separate trace impurities, but older techniques such as thin layer chromatography (TLC), fractional crystallization, fractional distillation, and solvent extraction are still very important. However, the classical methods of identification by preparation and characterization of derivatives have been almost completely replaced by modern spectral methods of analysis. Elemental analysis, nuclear magnetic resonance spectroscopy (NMR), infrared spectroscopy (IR), and mass spectroscopy (MS) — especially GC/MS — are used almost exclusively for identification of unknown products.

In addition to identification of degradation products, it is necessary to measure the rates of degradation of the drug and its formulations under a variety of conditions. This information is needed to define conditions for storage and handling that will assure potency and safety throughout the expected shelf life of the product. Stability studies are especially demanding of analytical precision and accuracy because changes of a few percent over a period of 3 to 5 years are significant and must be accurately quantitated. In order to be able to detect such small changes reliably with a limited number of replicate assays at each time point, the analysis must be very precise, free of interference from the degradation products, and free of "drift" due to changes in instruments, standards, operators, etc. over a period of years. Gas chromatography, high pressure liquid chromatography, spectrophotometric, titrimetric, and electrochemical metbods are all capable of adequate precision. Regardless of the method of measurement, the procedure must be carefully designed to avoid chemical interferences and the method precision must be determined experimentally for use in designing the stability study.

The set of analytical procedures developed to control the quality of the final marketed product must include both qualitative and quantitative methods in order to assure the identity and purity of the product. Several categories of tests are usually included in a product specification and these are summarized in Table 2. All the procedures called out in the specification must be amenable to routine use in a quality control laboratory and must therefore be as simple and rapid as possible. The procedures used during product development can often be simplified without loss of essential specificity or accuracy because the real problems associated with the product have been defined by the developmental work. However, control limits on both the purity of the drug substance and the drug content of the finished formulation are usually very tight, thus requiring very precise quantitative procedures for testing compliance. The preferred solution to the problem of quantitative control assays is therefore to use

HPLC or GC methods which afford simplicity, high speed, good specificity, and excellent precision and accuracy. An alternate that may be chosen when suitable GC or HPLC systems cannot be found, or for facilities where these instruments are not readily available (a common problem in some foreign countries), is to combine a precise but nonspecific quantitative assay with a qualitative chromatographic test that shows the absence of interfering impurities. This approach is widely used in the compendia and in control procedures for older products. The quantitative analysis in these cases is often a titrimetric or spectrophotometric method, and the qualitative test a thin layer or paper chromatogram. Regardless of the methods chosen for the final measurement, quantitative analysis of formulated products almost always requires a preliminary separation of the drug from excipients. This separation is frequently accomplished by extraction, solvent partitioning, filtration, or column chromatography, but many other techniques find occasional application. In spite of the multiplicity of methods available, finding a reasonably simple procedure that gives a clean, quantitative separation of the drug from the excipients is often the most difficult step in development of procedures for analyzing formulations.

In many cases, quantitative analysis of drugs also requires the use of an analytical reference standard of well defined purity. A reference standard is required whenever a relative technique such as GC, HPLC, ultraviolet, visible or infrared spectrophotometry, fluorometry, or polarography is used for the analysis. Standards are also required for some qualitative tests such as identification by retention time, retention volume, R₁ value. The evaluation of the reference standard is accomplished using a series of tests similar to those listed in Table 2 for analysis of the drug substance. However, relative analytical techniques cannot be used to obtain a purity value because of their requirement for a reference standard (area normalization is used to estimate purity from GC and HPLC traces, but the values obtained must be treated as rough approximations to the time purity). The purity value of the standard must instead be derived from absolute methods, i.e., methods which do not require a standard of the same substance. The available absolute methods are titrations and gravimetric procedures (including methods used for elemental analysis), NMR, coulometry, differential scanning calorimetry, and phase solubility analysis. The requirement for reference standards in analysis with a wide spectrum of applications in pharmaceutical development and control makes the absolute methods especially important in modern pharmaceutical analysis.

The range of problems encountered in pharmaceutical analysis coupled with the importance of achieving the highest specificity, precision, and accuracy possible result in new techniques for organic analysis being adopted quickly in the pharmaceutical industry. The purpose of this book is to review several of the newer methods that now find wide application in pharmaceutical analysis, as well as several older methods (e.g., phase solubility analysis and ultraviolet/visible spectroscopy) of unique importance. The principle of each technique is discussed with emphasis on factors that directly affect its proper application to analytical problems. A thorough understanding of these principles is essential when selecting instruments, operating conditions, and sample preparation procedures to optimize the performance of an analysis, or when trying to identify the cause of a failure encountered in an existing procedure. Tabulations of data useful in method development and applications are also presented, including tables of characteristic ir, nmr, and uv band positions; composition of standard buffer solutions; properties of solvents; and properties of column packings for GC and HPLC. Finally, selected applications of each technique to problems in pharmaceutical analysis are reviewed. It is hoped that the broad coverage given each of the selected techniques will make Modern Methods of Pharmaceutical Analysis useful as a source of ideas and guidance in developing practical solutions to problems in pharmaceutical analysis.

Table 1 ANALYTICAL TASKS IN DEVELOPMENT AND MARKETING OF A DRUG

Determination of identity and purity of starting materials and intermediates used in manufacturing the drug substance

Determination of the identity and purity of the drug substance
Isolation and identification of trace impurities in the drug substance
Determination of degradation rates and products for the drug substance
Determination of identity and purity of excipients used in manufacturing formulated products
Determination of degradation rates and products for the formulated drug
Establishment of an analytical reference standard for the drug substance

Table 2 OUTLINE OF QUALITY CONTROL TESTS FOR DRUG PRODUCTS

Identification Tests

Purpose: to confirm the identity of the principal component of a lot of raw material or formulation Types of tests: color tests, melting points of the drug or derivative of the drug, formation of precipitates, ir or nmr spectrum, mass spectrum, X-ray powder pattern, chromatographic mobility, optical rotation, refractive index, density

Quantitative Analysis of the Drug Substance

Purpose: to determine the percent purity of the drug substance or the content of the active ingredient(s) in a formulation

Types of tests: Absolute methods — titrations, gravimetric procedures, differential scanning calorimetry, coulometry, nuclear magnetic resonance spectrometry, phase solubility analysis

Relative methods — gas chromatography, high pressure liquid chromatography, spectrometry (utraviolet, visible, or infrared), fluorometry, polarography, microbiological assays

Tests for Specific Impurities

Purpose: to control the quantity of a specific impurity or group of inpurities in the drug product, such as water, solvents, metals, and trace organic impurities

Types of Tests: any test listed in Quantitative Analysis of the Drug Substance, atomic absorption, atomic emission, or semiquantitative limit tests using relative size of spots on thin layer chromatograms, spot tests with visual color comparison, etc.

Chromatographic Screen

Purpose: qualitative examination of the product for impurities, including contaminants not previously encountered

Types of tests: paper, thin layer, gas or high pressure liquid chromatography; electrophoresis; bioautography

Miscellaneous

Purpose: control of specific properties known to affect product performance or required by regulatory agencies

Types of tests: crystal form (X-ray or infrared spectroscopy), sterility, pyrogens, particle size, foreign matter, density, color, odor, etc.

THE EDITOR

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Dr. Schirmer is a member of the American Association for the Advancement of Science, American Chemical Society, Society for Applied Spectroscopy, American Physical Society, and the Academy of Pharmaceutical Sciences of the American Pharmaceutical Association. He has a number of publications in the areas of pharmaceutical analysis and applications of nmr to problems in chemical kinetics and structure, including a book, *The Nuclear Overhauser Effect* co-authored with Dr. Joseph Noggle.

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Chapter 1

NUCLEAR MAGNETIC RESONANCE SPECTROSCOPY

Roger E. Schirmer

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I.INTRODUCTION

Nuclear magnetic resonance (NMR) spectroscopy is the branch of spectroscopy dealing with the absorption of radio frequency radiation by substances held in a magnetic field. Absorption results from interaction of the radiation with the magnetic moment of nuclei in the sample, and it occurs at different frequencies for nuclei in chemically different environments within a molecule (Figure 1). Because the dependence of frequency on chemical environment is relatively simple, NMR has become an extremely important tool for elucidation of molecular structure, including stereochemistry and conformation. The sensitivity of the NMR spectrum to molecular structure makes it an excellent choice for identification testing in pharmaceutical analysis.

NMR also offers several unique advantages as a quantitative analytical technique. First, it is an absolute quantitative technique, in the sense that a reference standard of the substance being analyzed is not required. Proper choice of the absorption band used in an analysis will often yield a very specific assay which requires very little sample preparation prior to measurement. Finally, NMR is applicable to a very wide range of organic and inorganic compounds.

The principle disadvantages of NMR are the high cost of the instrument and its lack of sensitivity. Under typical operating conditions, a minimum 10 mg sample is required for NMR analysis. Use of signal averaging, high magnetic field strengths, and other special techniques can reduce the quantity of sample to as low as $10 \mu g$ in favorable cases, but only with a considerable loss of convenience. Nonetheless, many quantitative applications of NMR in pharmaceutical analysis have been reported in the literature, and the number of applications can be expected to increase rapidly in the future.

II. THEORY OF NMR

The theory of NMR is treated in numerous reference books at the elementary, 1-7 intermediate, 8.9 and advanced levels. 10 The theory will be reviewed here only to the extent necessary to provide a basis for discussing the applications of NMR in pharmaceutical analysis.

A. Nuclear Magnetic Moments

One of the physical properties characterizing a nucleus is its angular momentum. The maximum observable value of the angular momentum is $\hbar I$, where $h = h/2\pi$ where h is Planck's constant and I is the spin quantum number of the nucleus. I is restricted to integral and half integral values. A nucleus with spin I has 2I + 1 states with corresponding observable components of the angular momentum of $\hbar I$, $\hbar (I-1)$, $\hbar (I-2), \ldots, \hbar (-I)$.

Nuclei for which I is not zero also have a magnetic moment which is parallel to the angular momentum vector. The magnitudes of the observable components of the angular momentum and magnetic moment are related by $\mu = \gamma$ (\hbar I) where γ is the gyromagnetic ratio of the nucleus. If the magnetic moment of the nucleus is μ , the maximum observable components of μ are given by $m\mu/I$ where m is the magnetic quantum number and may assume values I, I = 1, I = 2,..., -I. The 2I + 1 values of the observable component of the magnetic moment correspond to the 2I + 1 angular momentum states of the nucleus. In the absence of electromagnetic fields, all 2I + 1 states will have the same energy.

When the spin quantum number of a nucleus is greater than ½, the nucleus will have an electric quadrupole moment in addition to its magnetic moment. This is of considerable importance in NMR spectroscopy because the electric quadrupole moment allows the nucleus to interact with electric as well as magnetic fields, and the electric field interactions are often much stronger than the magnetic interactions. As will be seen a little later, this has an important effect on the width and fine structure in an NMR band. Table 1 lists nuclei with nonzero values of I along with their quadrupole moments and natural abundances. All the elements listed in the table can be studied using NMR techniques. A useful relation between the atomic number (Z), isotopic mass (A) and nuclear spin I is displayed in the following:

- 1. I is half-integral if A is odd
- 2. I is zero if both A and Z are even
- 3. I is integral if A is even but Z is odd

As indicated above, only nuclei with nonzero values of I will have NMR spectra.

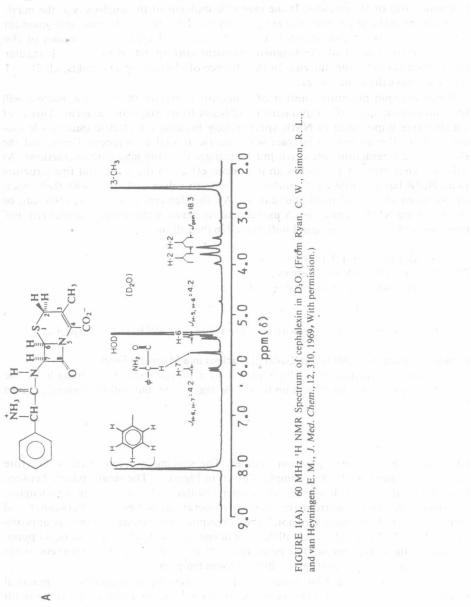
B. Nuclear Energy Levels for an Isolated Nucleus in a Magnetic Field

If a magnetic nucleus (I = 0) is placed in a magnetic field of strength H, the 2I + 1 nuclear energy levels will no longer be degenerate, but will have energies given by

$$E_{m} = m\gamma \hbar H \tag{1}$$

where m is the magnetic quantum number. The spacing between levels is therefore γ $\hbar H$, and is quite small. An example is given in Figure 2. The small spacing between levels limits the absorption of electromagnetic radiation to rather long wavelengths. In particular, NMR spectrometers normally operate at wavelengths between 1 and 300m in the radiofrequency region. The corresponding frequency range is approximately 1 to 350 MHz. The small difference in energy also leads to almost equal populations for the energy levels. The populations of the upper and lower magnetic states will differ only by a few parts per million at room temperature.

The very small population differences have important implications for practical NMR spectroscopy. Net absorption of energy from a radiofrequency field is the result of transitions of nuclei from lower to higher nuclear energy levels, and will only occur when the lower level has a greater population than the upper. As the excess is only one in a million at room temperature, a maximum of one out of every million nuclei is able to participate in energy absorption at a given instant, which is a major cause of the low sensitivity of NMR compared to other spectroscopic techniques. Once excited to an upper level, nuclei are often very slow to return to the lower level: half lives of excited states for a number of frequently studied nuclei including ¹H and ¹³C are on the order of seconds. A radiofrequency field of moderate intensity can cause upward transitions more rapidly than the nuclei can relax back to the lower states.



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60 MHz ¹H NMR Spectrum of cephalexin in D₂O. (Frd²m Rygen, E. M., J. Med. Chem., 12, 310, 1969, With permission.)

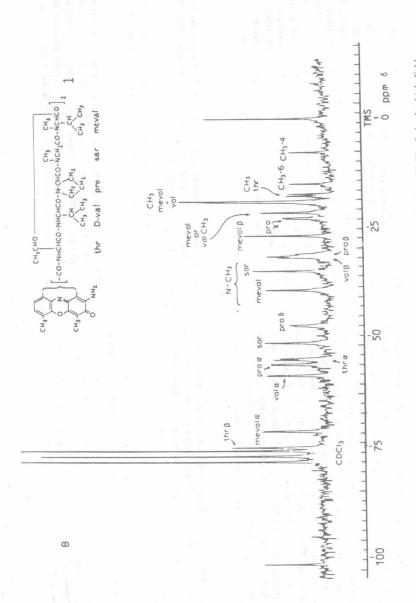


FIGURE 1(B). 25.15 MHz noise decoupled ¹³C NMR spectrum of actinomycin D in CDCl₃. Only the high field portion of the spectrum (0 to 120 ppm with respect to TMS) is shown. (From Booth, H., Mauger, A. B., and Rzeszotarski, W. J., Org. Magn. Reson., 8, 219, 1976. With permission.)

band

perfine structure,

optical spectroscopy (hy-

C

nuclear spin in units of h/2n magnetic moment in units of the nuclear magneton

element

eh/4nMc

EB

structure, double resonance, or optical pumping)

quadrupole resonance

NUCLEAR SPINS, MOMENTS, AND MAGNETIC RESONANCE FREQUENCIES Table 1

Kenneth Lee and Weston A. Anderson

| | 1961 | |
|---|------|--|
| This table contains the published values for the nuclear spins, magnetic moments, and | | |
| quadrupole moments, and the calculated values for the nuclear magnetic resonance | | |
| (NMR) frequency and for the relative sensitivities. Only those isotopes with both pub- | | |
| lished spin and magnetic moment values are tabulated. The magnetic and quadrupole | | |
| moment values were selected from results published during the period from January, | | |
| 1955 to June, 1967. Earlier references were obtained from H. E. Walchi, A Table of | | |
| Nuclear Moment Data, U.S. Atomic Energy Commission Report ORNL-1469, Sup- | | |
| plement I (1953) and Supplement II (1955), and D. Streminger, J. M. Hollander, and | | |
| G. T. Seaborg, Table of Isotopes, Rev. Mod. Phys. 30, 585 (1958). A table containing | | |
| the known (1963) spin and electromagnetic moment values of nuclear ground and ex- | | |
| cited states has been compiled by I. Lindgren, Perturbed Angular Correlations; E. | | |
| Karlsson, E. Mathias, and K. Siegbahn, editors; North-Holland Publishing Co. (1964). | | |
| The magnetic moments given in this latter table are corrected for the diamagnetic effect. | | |
| A more complete list of spin and moment results for nuclei in excited states are included | | |
| in Lindgren's table. | | |

In general, the results chosen for this table were selected with an inclination to NMR measurements and to the precision of the measurement. Only six significant figures are used in this table. Therefore, the number of figures may be less than those published. The experimental methods employed in determing the moments are indicated by the following symbols:

| | = molecular (or diamagnetic) | 11 | Mb | |
|------------------|------------------------------|----|----|--|
| Other symbols us | nance or other method) | | | |
| | ture, double or triple reso- | | | |
| N = nucle | onance (hyperfine struc- | | | |
| Mo = Moss | = atomic beam magnetic res- | H | Ab | |

ar magnetic resonance bauer effect

sed in the table are:

11 V

beam magnetic resonance

miscellaneous

li Mc

These expressions assume an equal number of nuclei, a constant temperature, and T₁ = T₂ (the longitudinal relaxation time equals the transverse relaxation time). These sensitivities represent the ideal induced voltage in the receiver coil at saturation and with a constant noise source. The calculated values are therefore determined under complete optimum conditions and should be regarded as such. atomic weight (mass num-

magnetic moment observed assumed or estimated valunits of barns (10-24 cm2) quadrupole moment radioactive isotope atomic number by NMR 0 in electron spin resonance or electron-nuclear double resmicrowave absorption metastable excited state nuclear orientation

onance

gases

S

was calculated for a total field of 104 gauss. The sensitivites, relative to the proton, are Assuming a nuclear magneton value of 5.0505 × 10⁻²⁴ erg/gauss, the NMR frequency calculated from the following expressions:

Sensitivity at constant field = $7.652 \times 10^{-3} \mu^2 (I+1)/I^2$ Sensitivity at constant frequency = $0.2387 \mu(I+1)$.

| | 1 | Method | Ab | Ab | Ab Ab | | 0 | , | | ; | Σ | | | Ab | | 田 | B | 00 | Ab | Ab | $\Sigma \Sigma$ | | MAb |
|--|--|--|---|--|---|--|--|---|---|--|---|---|---|--|---|--|---|---|--|---|---|---|--|
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| Electric Quadrupole Moment O | ples (s) | In multip sarsed to most oil) | -0.26 0.14 | 0.37 | 0.12 -0.22 1.5x10 ⁻² | | -4x10-2 | 1410 | | | 0.55 | 1 | | 0.40 | | -0.16 | -0.15 | -2.4x10-2 | 3.1x10-2 0.178 | 0.112 | 000 | 2 | 0.9 |
| 8.1 | 1 | Method | NN AP Ab | AP | Ab Ab | ZZ | EZZ | N S | Ab | No | E Ab | ANG O | 阿田 | N I | ANE AP | N A | NA P | OZ | APN | AP | dZZ | °ZZ | Ab |
| tic it 4 | 9 | Эспэтэгэд | 54 55 56 57 | | | 62 | | 66 | 68 | 70 | 73 | 422 | 72 | | 80 81 | | | | | | | | 91 |
| Magnetic Moment µ | lo asio | In multip the nucles magneton (eh/4±Me | -1.5924 -1.3153 4.61 2.56 | 3.96 | 3.03 5.33 0.095 | -0.78710 | 3.3413 | -0.47354 | 5.05 | (2.2) | 3.240 | 0.09024 4.6 3.95 | 4.65 | 4.5163 | 3.800 -0.74868 2.13 | 2.2206 | 2.3789 | 0.7692 | 0.0117 | 2.5549 | 0.55 | -0.906 | 0.5325 -1.02 (-)0.548 |
| Sensi- for | | At constant frequency | 1.71 1.41 4.95 1.83 | 6.62 | 3.62 5.73 0.102 | 0.658 | 5.58 | 0.283 | 5.73x10 ⁻² 5.42 | 1.58 | 3.09 | 3.23x10 ⁻² 4.94 4.60 | 4.99 | 4.96 | 5 44 0.447 1.27 | 1.33 | 1.42 | 0.643 | 5.59x10-8 | 0.126 | 1.15 | 0.649 | 0.191 1.10 0.262 |
| Relative Sensi- tivity for | of Nuclei | At constant blad | 1.14x10 ⁻³ 6.40x10 ⁻³ 0.275 9.63x10 ⁻² | 9.24x10 ⁻² 0.301 | 6.65x10-2 0.426 2.40x10-6 | 2.09x10-3 | 0.249 5.55x10 ⁻² | 9.03x10-4 | 2.9x10 ⁻⁹ 0.362 | 6.11x10 ⁻² 5.98x10 ⁻² | 0.175 | 3.37x10 ⁻⁵ 0.274 0.136 | 0.283 | 0.277 | 3.57x10-3 | 9.31x10-2 | 0.114 | 1.95x10 ⁻⁸ | 2.45x10-8 6.91x10-3 | 0.142 7.80x10-6 | 1.40x10-8 | 4.27x10-3 | 2.98x10 -8 2.98x10 -8 2.52x10 -8 |
| , | % 93 | latutaN onabnudA | 0.145 | 100 | HII | 7.28 | 0.24 | 9.55 | 11 | 1. | 100 | 2.19 | [] | 100 | 1.19 | 60.69 | 30.91 | 1 4 | 60.4 | 39.6 | 7.76 | 1 2 | 9c.1 |
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| F | | I niq8 | 2/25 | 6/2 | 7/2 | 2/2 | 7/2 | 3/2 | 1/2 | 38 | 3/2 | 7/2 | 7/2 | 1/2 | 3/2 | 3/2 | 3/2 | 5/2 | 3/2 | 3/2 | 2/5 | 225 | 1/2 |
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| Electric Quadrupole | Woment (| In multip of barns of 10-24cm ² Telerence | 2.73x10 ⁻³ 4 / | | | | | | 1.6x10-2 N | | = 1 | | | 0.14-0.15 32 0 | | | | | 42 | 43 | | 3 | |
| | 800 | Method In multip to barns (10-24cm ² | 4 | 1 | 10 | 5.2x10-2 14 | 16 | Ab | N 1.6x10-2 | Ab -2.6x10-2 25 | - L | N Ab | Ab | AD N 0.14-0.15 | | 36 | | -6.4x10-2 40 4.5x10-2 40 | N -7.89x10 ⁻³ 42 N -1.72x10 ⁻³ 44 | N -6.21x10 ⁻³ 43 | N 0.11 49 | Mb | Ab |
| | 800 | Reference Method In multip of barns of barns (10-24cm ² | 4 | 1 | 6.9x10 ⁻⁴ 9 -3x10 ⁻² 10 | 5.2x10-2 14 | 15 N 7.4x10 ⁻² 16 17 N 3.55x10 ⁻² 16 | 19 Ab — | N 1.6x10-2 | Ab -2.6x10-2 25 | 26 N 17 N | 27 N 28 Ab | 29 Ab 30 Ab | | | 36 | 38 N N | N -6.4x10-2 40 | N -7.89x10 ⁻³ 42 N -1.72x10 ⁻³ 44 | -6.21x10-3 42 | N 0.11 49 | 51 Mb | 52 Ab 53 Ab |
| Magnetic Electric Moment μ Quadrupole | (0) | Method In multip to barns (10-24cm ² | 4 | 0 N 1 | 6.9x10 ⁻⁴ 9 -3x10 ⁻² 10 | 5.2x10-2 14 | 7.4x10-2 16 3.55x10-2 16 | 19 Ab — | N 1.6x10-2 | 23 Ab -2.6x10 ⁻² 25 | 2.62727 17 N | 2.093 27 N -1.886 28 Ab | -0.65140 29 Ab 2.3861 30 Ab | 31 AD 17 N 0.14-0.15 | 34 Ab | 35 N 0.149 36 | 1.1306 38 N | 37 N -6.4x10 ⁻² 40 | 91 8 N -7.89x10 ⁻² 42 8 43 N -1.72x10 ⁻² 44 | 45 N -6.21x10 ⁻² 42 240 O | N 0.11 49 | Mb | |
| Magnetic Moment μ | 10 sold 1 | the nucles magneton (ch/ 4+ Mc (ch/ 4+ Mc Reference Method In multip of barns of barns (10 ⁻²⁴ cm ² | 1 Ab | -2.1274 6 N - | 8 N 6.9x10 ⁻⁴ 9 8 N -3x10 ⁻² 10 11 Ab | -1.1774 . 12 N 5.2x10 ⁻² 14 | 15 N 7.4x10 ⁻² 16 17 N 3.55x10 ⁻² 16 | (-)0.322 19 Ab | 20 N 1.6x10-2 | 23 Ab -2.6x10 ⁻² 25 | 2.62727 | | | 2,2161 17 N 0.14-0.15 | 1.690 34 Ab -0.85449 13 N | 3.6385 35 N 0.149 36 | 1.1305 | 0.64257 37 N -6.4x10 ⁻² 40 | 0.82091 8 N -7.89x10-3 42 1.2838 43 N -1.72x10-3 44 | 45 N -6.21x10 ⁻² 42 240 O | 0.39007 47 N 0.11 49 | -1.296 51 Mb | |
| | 10 sold 1 | constant frequency in multip the nucles magneton (eh/ 4= Mc Method Method in multip of barns of barns | -1.91315 1 Ab 2.79288 2 N 0.857387 3 N 2.73x10 ⁻³ 4 | .442 0.762 -2.1274 6 N - | 0.82192 8 N 6.9x10 ⁻⁴ 9 3.2560 8 N -3x10 ⁻² 10 1.653 11 Ab | 0.703 -1.1774 · 12 N 5.2x10 ⁻² 14 | 1.8007 15 N 7.4x10 ⁻² 16 2.6880 17 N 3.55x10 ⁻² 16 0.709100 18 N | 0.115 (-)0.322 19 Ab | 0.193 0.40347 21 N 1.6x10-r | 0.719 23 Ab -2.6x10 ⁻² 25 | 0.941 2.62727 | 1.50 | 0.395 -0.65140 | 1.32 2.2161 17 N 0.14-0.15 | 2.02 1.690 34 Ab 0.714 -0.85449 13 N | 3.04 3.6385 35 N 0.149 36 | 0.406 1.1305 | 0.583 0.64257 37 N -6.4X10 ⁻² 40 0.597 1.00 41 M 4.5X10 ⁻² 40 | 0.490 0.82091 8 N -7.89x10 ⁻³ 42 0.919 1.2838 43 N -1.72x10 ⁻³ 44 | 0.6833 45 N -6.21x10 ⁻³ 42 1.0 240 O | 0.233 0.39097 47 N 0.11 49 | 1.55 -1.296 51 Mb | 0.21459 -1.140 0.163 |
| Magnetic Moment μ | of Nuclei | At constant frequency the multip the nucles magneton (eh/##Mc Reference Method Method of barns of barns of Darns | 0.322 0.685 -1.91315 1 Ab 1.00 1.00 2.79288 2 N -2.733.10** 4 9.655.10** 0.450** 0.85737* 3 N -2.733.10** 4 1.21 1.77 2.97877 5 N | 0.442 0.762 -2.1274 ⁶ N - | 8.50x10 ⁻³ 0.392 0.82192 8 N 6.9x10 ⁻⁴ 9 0.293 1.94 3.2560 8 N -3x10 ⁻² 10 2.59x10 ⁻² 1.184 1.653 11 Ab | 1.39x10 ⁻² 0.703 -1.1774 13 N 5.2x10 ⁻² 14 | 1.99x10 ⁻² 1.72 1.8007 15 N 7.4x10 ⁻² 16 0.165 1.60 2.6890 17 N 3.5x10 ⁻² 16 1.6x10 ⁻² 16 | 1.53x10-3 0.115 (-)0.322 19 Ab | 1.01x10 ⁻⁸ 0.193 0.40347 20 N 1.6x10°2 1.04x10 ⁻⁸ 0.101 -0.28398 20 N | 1,70x10 ⁻² 0.257 0.719 23 Ab 291x10 ⁻² 1.58 -1.8930 24 N -2.6x10 ⁻² 25 | 0.833 0.941 2.62727 | 5.26x10 ⁻¹ 1.50 0.308 0.675 | 2.50x10-9 0.395 -0.65140 0.116 1.42 2.3861 | 1.51X10 2 1.07 1.746 31 AD 9.25X10 ⁻² 1.32 2.2161 17 N 0.14-0.15 | 1.15x10 ⁻² 2.02 1.690 34 Ab 2.67x10 ⁻³ 0.714 -0.85449 13 N | 7 84-10-8 0.100 -0.55477 37 N | 6.63x10-7 0.406 1.1306 | 2.26x10** 0.383 0.64257 37 N -6.4x10** 40 2.26x10** 0.597 1.00 41 M 4.5x10** 40 | 4.70x10 ⁻³ 0.490 0.82091 8 N -7.89x10 ⁻³ 42 1.21x10 ⁻³ 0.919 1.2838 43 N -1.72x10 ⁻³ 44 | 2.71x10 ⁻⁸ 0.408 0.6833 45 N -6.21x10 ⁻² 42 8.50x10 ⁻⁸ 0.597 1.0 240 0 | 8.82x10 | 5.21x10-8 1.55 -1.296 51 Mb | 8.50x10 ⁻⁸ 0.816 -1.140 3.68x10 ⁻⁶ 9.73x10 ⁻³ 0.163 |
| Relative Sensi- Magnetic tivity for Moment µ | of Nuclei of O | At constant blad blad blad constant constant constant frequency. In multiple blad constant co | 99.985 1.00 1.00 2.7988 2 N — 1.811.1 1.07 2.7987 3 N 2.73x10 ⁻¹ 4 | 1.3x10-4 0.442 0.762 -2.1274 6 N | 8.50x10 ⁻³ 0.392 0.82192 8 N 6.9x10 ⁻⁴ 9 0.293 1.94 3.2560 8 N -3x10 ⁻² 10 2.59x10 ⁻² 1.184 1.653 11 Ab | 100 1.39x10-2 0.703 -1.1774 . 12 N 5.2x10-2 14 | 19.58 1.99x10 ⁻² 1.72 1.8007 15 N 7.4x10 ⁻² 16 80.42 0.165 1.60 2.6880 17 N 3.5x10 ⁻² 16 1.00 7.00x100 18 N 3.5x10 ⁻² 16 | 1.100 1.2810 0.201 0.10119 10 IN - 1.5310 0.115 (-)0.322 90 | 99,63 1.01x10 ⁻⁸ 0.193 0.46347 21 N 1.6x10 ⁻⁸ 0.37 1.04x10 ⁻⁸ 0.101 -0.28298 ²⁰ N - | 1,70x10 ⁻² 0.257 0.719 23 Ab 291x10 ⁻² 1.58 -1.8930 24 N -2.6x10 ⁻² 25 | 100 0.833 0.941 2.62727 | - 5.26x10 ⁻¹ 1.50 - 0.308 0.675 | 0.257 2.50x10 ⁻³ 0.395 -0.65140 0.116 1.42 2.3861 | 100 9.25x10 ⁻² 1.32 2.2161 17 N 0.14-0.15 | 10.13 2.67x10 ⁻³ 0.714 -0.85449 13 N | 100 0.206 3.04 3.6385 35 N 0.149 36 | 100 6.63x10 ⁻² 0.406 1.1305 | 0.76 2.26x10 ⁻⁸ 0.383 0.64257 37. N -6.4x10 ⁻³ 40 — 8.5x10 ⁻⁸ 0.597 1.00 41 M 4.5x10 ⁻³ 40 | 75.53 4.70x10 ⁻² 0.490 0.82091 8 N -7.89x10 ⁻³ 42. | 24.47 2.71x10 ⁻² 0.408 0.6833 45 N -6.21x10 ⁻² 42 | 93.10 5.08x10 ⁻⁴ 0.233 0.39097 48 N 0.11 49 | 1.18x10-2 5.21x10-3 1.55 -1.296 51 Mb | 8.50x10 ⁻⁸ 0.816 -1.140 3.68x10 ⁻⁶ 9.73x10 ⁻³ 0.163 |
| Relative Sensi- Magnetic tivity for Moment µ | of Nuclei of O | January Matural Mandand A. January M. Januar | 99.985 1.00 1.00 2.7988 2 N — 1.811.1 1.07 2.7987 3 N 2.73x10 ⁻¹ 4 | 32.433 1.3x10 ⁻⁴ 0.442 0.762 -2.1274 ⁶ N - | 7.42 8.5x10°* 0.392 0.82192 8 N 6.x10°* 9 92.58 0.283 1.94 3.2860 8 N -3x10°* 10 - 2.59x10°* 1.84 1.633 11 Ab | 5.9834 100 1.39x10-2 0.703 -1.1774 12 N 5.2x10-2 14 | 19.58 1.99x10 ⁻² 1.72 1.8007 15 N 7.4x10 ⁻² 16 80.42 0.165 1.60 2.6880 17 N 3.5x10 ⁻² 16 1.00 7.00x100 18 N 3.5x10 ⁻² 16 | 4.91 1.53x10 ⁻³ 0.115 (-)0.322 19 Ab | 3.0756 99.63 1.01x10 ⁻³ 0.183 0.40347 21 N 1.6x10 ⁻² 4.3142 0.37 1.04x10 ⁻³ 0.101 -0.28398 ²⁰ N - | 3.7x10-2 2.91x10-3 1.58 -1.8930 24 N -2.6x10-3 25 | 40.0541 100 0.833 0.941 2.62727 | 7.977 — 5.26x10 ⁻¹ 1.50 28.75 — 0.308 0.675 | 3.3611 0.257 2.50x10 ⁻³ 0.395 -0.65140 12.126 -0.116 1.42 2.3861 | 4.456 1.31x10 1.00 1.746 31 AD 11.262 100 9.25x10 1.32 2.2161 17 N 0.14-0.15 | 3.221 — 1.15x10 ⁻² 2.02 1.690 34 Ab 2.6054 10.13 2.67x10 ⁻³ 0.714 -0.85449 13 N | 11.094 100 0.206 3.04 3.6385 35 N 0.149 36 8.4778 4.70 7.54710 0.100 -0.54477 37 N | 7.235 100 6.63x10 ⁻² 0.405 1.1305 1.000 0.4x407-4 0.190 0.005 | 3.2654 0.76 2.26810" 0.383 0.64257 37, N -6.4x10" 40 | 4.1717 75.53 4.70x10 ⁻¹ 0.490 0.82091 8 N -7.89x10 ⁻¹ 42.48931 1.2838 43 N -1.72x10 ⁻¹ 44 | 3.472 24.47 2.71x10 ⁻¹ 0.408 0.6833 45 N -6.21x10 ⁻¹ 42 5.08 - 8.50x10 ⁻¹ 0.597 1.0 240 O | 3.491 — 8.82x10* 1.31 1.374 40 AD 1.9868 93.10 5.08x10^4 0.233 0.39097 47 N 0.11 49 | 2.470 1.18x10 ⁻² 5.21x10 ⁻³ 1.55 -1.296 51 Mb | 4.345 — 8.50x10" 0.126 0.21459 0.828 — 8.50x10" 0.816 -1.140 |
| Relative Sensi- Magnetic tivity for Moment µ | of Nuclei of O | MMR Free | 99.985 1.00 1.00 2.7988 2 N — 1.811.1 1.07 2.7987 3 N 2.73x10 ⁻¹ 4 | 32.433 1.3x10 ⁻⁴ 0.442 0.762 -2.1274 ⁶ N - | 6.546.3 7.42 8.65010°* 0.392 0.82192 8 N 6.510°* 9 16.546 9.530 | 5.9834 100 1.39x10-2 0.703 -1.1774 12 N 5.2x10-2 14 | 4.5754 19.58 1.99x10 ⁻³ 1.72 1.8007 15 N 7.4x10 ⁻³ 16 13.60 80.42 0.165 1.60 2.8880 17 N 3.5x10 ⁻³ 16 1.70 1.70 1.70 1.70 1.70 1.70 1.70 1.70 | 1/2 4.91 - 1.53x10 ⁻³ 0.115 (-)0.322 19 Ab - | 1 3.0756 96.63 1.01x10 ⁻³ 0.193 0.40347 21 N 1.6x10 ⁻² 1/2 4.3142 0.37 1.04x10 ⁻³ 0.101 -0.28298 ²⁰ N - | 11.0 — 1.70x10 ⁻³ 0.287 0.719 23 Ab — 5.772 3.7x10 ⁻³ 2.9xx10 ⁻³ 1.58 —1.8930 24 N —2.6x10 ⁻³ 25 | 3/2 14.40 — 0.451 5.94 4.720 1/2 40.0541 100 0.833 0.941 2.62727 | 2 7.977 — 5.26x10 ⁻² 1.50 (1/2) 28.75 — 0.308 0.675 | 3/2 3.3611 0.257 2.50x10 ⁻³ 0.395 -0.68140 3/2 12.126 -0.116 1.42 2.3861 | 3/2 11.262 100 9.25x10 ⁻² 1.32 2.2161 17 N 0.14-0.15 | 4 3.221 — 1.15x10 ⁻² 2.02 1.690 34 Ab 5/2 2.6054 10.13 2.67x10 ⁻³ 0.714 -0.85449 13 N | 5/2 11.094 100 0.206 3.04 3.6385 35 N 0.149 36 | 1/2 17.235 100 6.63x10 ⁻² 0.405 1.1305 1 1.000 0.63x10 ⁻³ 0.405 1.1305 | 3/2 2.864 0.76 2.86x10" 0.383 0.64257 37 N -6.4x10" 40 | 3/2 4.1117 75.53 4.703.10" 0.490 0.82091 8 N -7.893.10" 42 2 4.8931 1.213.10" 0.919 1.2838 43 N -1.723.10" 44 | 3/2 3.472 24.47 2.71x10 ⁻² 0.408 0.6833 45 N -6.21x10 ⁻³ 42 3/2 5.08 — 8.50x10 ⁻³ 0.597 1.0 240 O | 3/2 1.9968 93.10 5.08x10 ⁻⁴ 0.233 0.39007 47 N 0.11 49 | 4 2.470 1.18x10 ⁻³ 5.21x10 ⁻³ 1.55 -1.296 51 Mb | 3/2 0.828 — 3.68x10 ⁻⁶ 9.73x10 ⁻⁷ 0.163 |
| Relative Sensi- Magnetic tivity for Moment µ | of Nuclei of O | I niqg M.H. in the in the interpretation of | 99.985 1.00 1.00 2.7988 2 N — 1.811.1 1.07 2.7987 3 N 2.73x10 ⁻¹ 4 | 32.433 1.3x10 ⁻⁴ 0.442 0.762 -2.1274 ⁶ N - | 6.546.3 7.42 8.65010°* 0.392 0.82192 8 N 6.510°* 9 16.546 9.530 | 5.9834 100 1.39x10-2 0.703 -1.1774 12 N 5.2x10-2 14 | 3 4.574 19.58 1.99x10 ⁻³ 1.72 1.8007 15 N 7.4x10 ⁻³ 16 3/2 13.860 80.42 0.1055 1.60 2.8680 17 N 3.5x10 ⁻³ 16 1/2 10.91 10.8 1.5x10 ⁻³ 16 | 13* 1/2 4.91 - 1.53x10" 0.115 (-)0.322 19 Ab - 2.53x10" 0.115 | 14 1 3.0756 99.63 1.01x10 ⁻³ 0.193 0.40347 21 N 1.6x10 ⁻² 15 1/2 4.3142 0.37 1.04x10 ⁻³ 0.101 -0.28598 ²⁰ N - | 1/2 11.0 1.0 1.70x10 ⁻³ 0.257 0.719 23 Ab 2.5 5.772 3.77210 ⁻³ 291x10 ⁻³ 1.58 1.58 1.8830 24 N -2.6x10 ⁻³ 25 | 17 5/2 14.40 — 0.451 3.94 4.720 19 1/2 40.0541 100 0.833 0.941 2.62727 | 20° 2 7.97 — 5.26x10 ⁻¹ 1.50 19° (1/2) 28,75 — 0.308 0.675 | 21 3/2 3.3611 0.257 2.50x10 ⁻⁴ 0.395 -0.65140 21° 3/2 12.126 -0.116 1.42 2.3861 | 23 3/2 11.262 100 9.25x10 ⁻² 1.32 2.2161 17 N 0.14-0.15 | 24" 4 3.231 — 1.15x10" 2.02 1.690 34 Ab 25 5/2 2.6054 10.13 2.67x10" 0.714 -0.85449 13 N | 27 5/2 11.094 100 0.206 3.04 3.6385 35 N 0.149 36 | 31 - 1/2 17.235 100 6.63x10 ⁻³ 0.405 1.1305 | 33 3/2 3.2654 0.76 2.26510** 0.383 0.64257 37. N -6.4x10** 40 | 35 3/2 4.1717 75.53 4.70x10 ⁻⁸ 0.490 0.83091 8 N -7.89x10 ⁻³ 43 38° 2 4.89x1 1.21x10 ⁻³ 0.919 1.2838 43 N -1.72x10 ⁻³ 44 | 37 3/2 3.472 24.47 2.71x10 ⁻¹ 0.408 0.6833 45 N -6.21x10 ⁻¹ 42 37° 3/2 5.08 - 8.50x10 ⁻¹ 0.597 1.0 240 0 | 35 5 3.491 — 8.82Z10* 1.51 1.374 40 AD 39 3/2 1.9868 93.10 6.08X10* 0.233 0.39097 47 N 0.11 49 | 40° 4 2.470 1.18x10 ⁻² 5.21x10 ⁻⁸ 1.55 -1.296 51 Mb | 41 3/2 1.0905 0.88 8.90x10 ⁻³ 0.1359 42° 2 4.345 — 8.50x10 ⁻³ 0.816 -1.140 43° 3/2 0.828 — 3.68x10 ⁻³ 9.73x10 ⁻³ 0.163 |

| 1 1- | Method | 0 | O Ab | Ab | | | 0 | 0 | | ĭo5 | Ab | | | Ab | | 0 | 0 | AP | | |
|---|--|---|---|--|--|--|--|--|--|--|---|--|---|--|--|------------------------------------|---|--|-------------------------------|---|
| t Q | Кегепсе | 239 | 127 | 16 | | | 134 | 134 | | 138 | | 143 | | 146 | 143 | 153 | 153 | 154 | | |
| Electric Quadrupole Moment Q | In multiple of barns (10-24cm²) | -0.79 | -0.61 | 1.16 | 1 | 1.1 | 0.5 | 7.0- | 111 | 0.69 | -0.41 | 0.12 | F | -3x10 ⁻³ | 0.40 | 0.25 | 0.2 | 0.21 | | |
| 1 | Method | 00 | ozi | NAP | Ab Ab | ZZZ | zz'z | o z | ANN | Zzz | AN X | Ap | AP AP AP | Z Z | Ab | Ab N | Z | zzz | 0 0 0 ZZZ | |
| etic nt µ | Вегетепсе | | | | | | | | | 138 | | | 144 | | 150 | 151 | 151 | 154 | 157 | 158 |
| Magnetic Moment µ | In multiple the nuclear magneton (oh/4xMc) | -1.09 | -1.044 | 4.7 | 4.21 | -0.91320 | 3.3415 | 2.5334 | 0.27 | 2.7937 | 2.738 | 0.68697 | 1.47 1.4 3.517 | 2.56422 | 2.973 | 2.8219 | 0.93107 | 2.7615 | 0.69 | 0.97 |
| Sensi- for umber | At frequency | 1.69 | 7.22 | 6.73 7.23 | 8.73x10 ⁻² 6.03 6.30 | 0.356 | 2.79 | 2.72 | 9.67x10 ⁻² 0.262 0.316 | 2.51 | 2.94 | 0.512 | 0.526 0.668 2.94 | 2.75 | 3.55 2.36 2.91 | 3.03 | 0.556 | 5.28 | 1.07 | 1.04 |
| Relative Sensi- tivity for Equal Number of Nuclei | onstant bled | 2.13x10 ⁻⁸ | 1.87x10-3 0.345 | 4.28x10 * 0.191 0.347 | 6.64x10 ⁻⁴ 0.137 0.156 | 3.50x10 ⁻² | 0.160 | 3.94x10-2 4.57x10-2 | 9.04x10 ⁻⁴ 1.8x10 ⁻² | 0.116 9.34x10 ⁻² 4.96x10 ⁻² | 5.77x10-2 2.12x10-2 | 2.76x10 3 0.134 | 4.20x10 ⁻² 0.186 | 4.74x10 ⁻² | 6.28x10-3 1.42x10-3 5.62x10-2 | 6.32x10 ⁻² | 6.86x10 ⁻³ | 9.19×10 ⁻² 5.92×10 ⁻² | 6.20x10-4 | 2.57x10-3 |
| % | Natural SonsbaudA | 11 | 4.28 | 95.72 | 111 | 7.61 | 57.25 | 42.75 | 0.87 | 100 | 26.44 | 21.18 | | 100 | 111 | 6.59 | 11.32 | 0.089 | ! ! | 1.1 |
| nency 8 10 bld | NMR Freq in MHz for kilogauss fi | 1.51 | 1.447 | 3.209 7.2 9.3301 | 3.715 6.42 6.7 | 13.922 | 15.869 | 5,5176 | 4.12 | 9.0 8.5183 5.6694 | 5.963 | 3,4911 | 22.4 10.7 10.72 | 5,58469 | 5.666 1.0447 5.9096 | 6.1459 | 4.7315 | 5.6171 | | |
| P- 047 | I niq8 | 11/2 | 11/2 | 1/2 5/2 | 5 5 2 | 1/2 | 5/2 | 7/2 | 222 | 1000 | 1222 | 3/2 | 1/2 | 7/2 | 7/804 | 3/2 | 3/2 | 5. | 3/2 | 2/2 |
| | A A | 113° | 115m 1113 | 113m 114m 115* | 115° 116° | 1115 | 119 | 123 | 1123 | 125° 127 | 131* | 127* | 129° 130° 131° | 133 | 134° 134° 135° | 137° | 137 | 138 | 137° | 141 |
| | Isotope | 33 | 384, | 225 | 222 | SSS | Ses a | Sp | Te | | Xe | Cs | చ్చి చ | 30 | చ్చి చ | Cs Ba | Ba | al al | ಲಿಲಿ | 00 |
| | | 848 | 488 | 49 49 69 | 49 | 20 20 | 50 | 51 • | 52 | | 253 | 54 | 55 | 92 22 | 55 | 55 | 56 | | 58 | 58 |
| - | | = | | | | | | | | | | | | | | | | | | |
| 1 | Method | Ab | Ab | 00 O | | Ab | Ab | Ab | | ozzo | | | | | | | | 00 | | |
| Electric Quadrupole Moment Q | Reference | 93 | 93 | 98 | | 10 | 101 | 105 | | | 4 | | | | | | | | | |
| dru | | | | | | - | | = | 5 | 109 | 1 | | | | | | | 123 | | |
| Q Qua Mo | In multiples of barns (10-24cm²) | 0.33 | 0.76 | 0.15 | | 0.27 | 0.13 | - | | 0.12 108 | | 1 | | ΙÍ | ı | | | 0.8 123 0.8 124 | ł | 1 |
| | Method In multiples of barns (10-24cm²) | | | 1 | Ab Ab | | 0.13 | -0.16 | 1 0 | | 200 | z | Ab Ab | Ab N | Ab - | Ab | Ab | 0.8 | N | 1 N |
| | Reference | N.A. | | QNO. | | Ab N | Ab N 0.13 N 0.2 | N Ab -0.16 | Ab N | 0.12 | Mo 0 | | | 47 N — | | | | 0.8 | 126 N | |
| Magnetic Λoment μ | Method | N.A. | 94 Ab 8 N | QNO. | 66 | Ab N | 102 Ab 103 N 0.13 66 N 0.2 | 47 N 105 Ab -0.16 | 60 Ab | NNN 0.1.2 | 112 Mo | 43 | 115 116 116 | | 1119 | 120 | 122 | 0 0.8 | -0.5922 126 N | |
| Magnetic Moment µ | magneton (eh/4 % Mc) Reference Method | 2.0900 8 N | 94 Ab 8 N | (+)1.626 95 Ab (- -0.9671 96 N -1.001 98 O | 2.05 99 | 99 Ab 100 N | -1.69 102 Ab 2.7414 103 N 0.13 -1.0803 66 N 0.2 | -2 -0.13682 47 N -1.62 105 Ab -0.16 | 2 0.163 60 Ab | 45 N 0.12 | -0.284 112 Mo -0.69 113 O | 2 -0.08790 43 | -0.639 115 4.0 116 3.7 116 | 47 | 4.2 119 | 3.587 120 | 0.0545 122 | 123 0 0.8 124 0 0.8 | | 125 |
| Magnetic Λoment μ | constant frequency in multiples the nuclear magneton (eh/4*h/c) Reference | 1.25 2.0900 8 N | 1.89 1.317 94 Ab | 2.33 (+)1.626 95 Ab (- 1.27 -0.9671 96 N 1.31 -1.001 98 O | 1.22 2.05 99 2.15 1.50 99 | 0.945 -1.32 99 Ab 1.13 1.3482 100 N | 1.21 -1.69 102 Ab 1.64 2.7414 103 N 0.13 1.43 -1.0893 66 N 0.2 | 4.90x10 ⁻² -0.13682 47 N -0.16 1.16 -1.62 105 Ab -0.16 | 5.84x10 ⁻² 0.163 60 Ab | 0.9997 45 N 0.12 -0.9289 45 N 1.1 | 0.169 -0.284 112 Mo 0.576 -0.69 113 O | 3.15x10-2 -0.08790 43 | -0.639 115 4.0 116 3.7 116 | 3.62x10 ⁻² 0.101 117 4.05x10 ⁻² -0.11301 47 | 2.01 4.2 119 47 | 5.99 3.587 120 | 3.90x10 ⁻² 0.0545 122 8.40x10 ⁻² 0.0545 122 | -0.6162 123 0 0.8 -0.8293 124 0 0.8 | -0.5922 | -0.6195 125 |
| Relative Sensi- Equal Number of Nuclei | held At constant frequency fr | 7.86x10-1 1.25 2.0900 8 N | 1.89 1.317 94 Ab | 7.90x10 ⁻³ 2.33 (+)1.626 95 Ab (- 1.88x10 ⁻³ 1.27 -0.9671 96 N 2.08x10 ⁻³ 1.31 -1.001 98 O | 7.32x10 ⁻² 1.22 2.05 99 6.20x10 ⁻³ 2.15 1.50 99 | 1.32x10 ⁻² 0.945 -1.32 99 Ab 1.05x10 ⁻² 1.13 1.3482 100 N | 2.77x10 ⁻² 1.21 -1.69 102 Ab 0.175 1.64 2.7414 103 N 0.13 2.60x10 ⁻³ 1.43 -1.0803 66 N 0.2 | 1.184x10 ⁻⁴ 4.90x10 ⁻² 0.13632 47 N — 2.44x10 ⁻³ 1.16 — 1.62 — 105 Ab — 0.16 | 1.99x10 ⁻⁴ 5.84x10 ⁻² 0.163 60 Ab 9.48x10 ⁻⁴ 1.09 -1.3024 1.06 N | 3.23x10 ⁻³ 0.760 0.9097 45 N 0.12 3.43x10 ⁻³ 0.776 0.9289 45 N 1.1 | 1.95.07 1.43 5.29.2 110 M 1.95.07 4.0.169 -0.284 112 Mo 1.41x10 ⁻⁸ 0.576 -0.69 113 O | 3.11x10-6 3.15x10-2 -0.08790 43 | 0.534 -0.639 115 5.73 4.0 116 2.65 3.7 116 | 6.62x10 ⁻⁶ 3.62x10 ⁻² 0.101 117 6.62x10 ⁻⁶ 4.05x10 ⁻² -0.11301 47 | 1.13 2.01 4.2 1119 | 6.87x10-2 5.99 3.587 120 | 9.00x10-7 3.90x10-7 0.0545 122 | 0.515 -0.6162 123 0 0.8 0.693 -0.8293 124 0 0.8 | 9.54x10-# 0.212 -0.5922 | 0.222 -0.6195 126 |
| Relative Sensi- Magnetic Livity for Moment # Squal Number of Nuclei of Nuclei w | Abundance of constant field field firequency lirequency in multiples the nuclear magneton magneton firequence | 50.54 7.96x10 ⁻¹ 1.25 2.0900 8 N | 49.46 9.85x10 2.2626 8 N | 1.55 1.88x10 ⁻³ 1.27 -0.9671 96 N -0.208x10 ⁻³ 1.37 -0.9671 96 O | - 7.32x10 ⁻² 1.22 2.05 99 6.20x10 ⁻³ 2.15 1.50 99 | 72.15 1.05x10 ⁻² 1.13 1.3482 100 N | 27.7x10 ⁻² 1.21 -1.69 102 Ab 0.13 27.85 0.175 1.64 2.7414 103 N 0.13 7.79 seeper 1.43 -1.0993 66 N 0.2 | 100 1.08x10 ⁻⁴ 4.90x10 ⁻² -0.13682 47 N | 11.23 9.45x10 ⁻⁴ 5.84x10 ⁻² 0.163 60 Ab | 100 0.4552 8.07 6.14507 40.012 11.1 15.72 3.233310-7 0.7760 0.9097 45 N 0.112 11.5.72 3.233310-7 0.7760 0.9098 45 N 0.11 | 12.72 1.95x10 ⁻⁴ 0.576 -0.69 113 0 | 100 3.11x10 ⁻⁵ 3.15x10 ⁻² -0.08790 43 | 1.12x10 ⁻³ 0.534 -0.639 115 0.118 5.73 4.0 116 0.291 2.65 3.7 116 | 51.82 6.62x10 ⁻⁵ 4.05x10 ⁻² 0.101 117 | 48 18 1 01 1 1 4 2 1 1 4 2 1 1 4 4 4 4 4 1 4 1 4 | 6.8710-3 5.99 3.587 120 | 9.00x10-7 3.00x10-2 0.0545 122 | - 1.00x10 ⁻³ 0.693 -0.8293 124 0 0.8 | 12.75 9.54x10-* 0.212 -0.5922 | 1.09x10 ⁻² 0.222 -0.6195 126 |
| Relative Sensi- Magnetic Livity for Moment # Squal Number of Nuclei of Nuclei w | Watural Watural Watural Abundance constant field At frequency In multiples frequency frequency (eh/4xNtc) Reference | 10.667 50.54 7.86x10 ⁻² 1.25 2.0900 8 N | 2.02 — 2.08XIU 1.249 1.317 94 Ab 11.498 49.46 9.85XIU 1.35 2.2626 8 N | 2.479 — 7.90x107* 2.33 (+)1.628 95 Ab (- 1.638 11.55 1.88x107 -0.9671 96 N 1.696 — 2.08x107 1.31 -1.001 98 O | 10.4 7.32x10 ⁻² 1.22 2.05 99 2.29 6.2010 ⁻³ 2.15 1.50 99 0.0010 ⁻³ 2.15 1.50 99 | 5.03 — 1.32x10 ⁻² 0.945 -1.32 99 Ab 4.1108 72.15 1.05x10 ⁻² 1.13 1.3482 100 N | 6.44 — 2,77x10 ⁻² 1.21 —1.69 102 Ab 13.931 27.85 0.175 1.64 2,741 103 N 0.13 1.450 7 70 2,0177 1.43 —1.0393 66 N 0.2 | 2.0859 100 1.18x10 ⁻⁴ 4.90x10 ⁻² -0.13882 47 N — 6.17 — 2.44x10 ⁻² 1.16 -1.62 N = 0.16 | 2.49 1.99x10 ⁻⁴ 5.84x10 ⁻² 0.163 60 Ab 3.97249 11.23 9.48x10 ⁻³ 1.09 30224 106 N | 10.407 100 0.482 8.0.1 0.185 107 N 0.12 2.774 15.72 2.832 9.46 8.63310 ⁻³ 0.776 0.9989 45 N 1.1 2.832 9.46 8.63310 ⁻³ 0.776 0.9989 45 N 0.8 | 8.5830 $-$ 0.507 $-$ 110 M 0.514 $-$ 127 1.58x10 ⁻⁴ 0.159 $-$ 0.284 112 M 0 $-$ 1.1 M 0 $-$ 1.1 M 1 1.4 110 ⁻⁴ 0.576 $-$ 0.69 113 O | 1.3401 100 3.11x10-5 3.15x10-7 -0.08790 43 | 22.23 1.12x10 ⁻³ 0.534 -0.639 115 - 0.118 5.73 4.0 116 - 0.291 2.65 3.7 116 | 1.54 — 4.73x10 ⁻⁶ 3.62x10 ⁻² 0.101 117 1.7229 51.82 6.62x10 ⁻⁶ 4.05x10 ⁻² -0.11301 47 | 32.0 — 1.13 2.01 4.2 110 1.0007 4.818 101v10 ⁻⁴ 4 46x10 ⁻² -0.19992 47 | 4.567 — 6.877.10** 5.99 3.587 120 | 2.21 — 1.40x10° 5.19x10° - 0.145 121 0.2077 — 9.00x10° 3.90x10° 0.0545 122 0.00x10° 0.00x10° 0.0545 122 | 2.529 — 2.44x10 ⁻³ 0.693 —0.8293 124 0 0.8 | 12.75 9.54x10-* 0.212 -0.5922 | 12.26 1.09x10 ⁻³ 0.222 -0.6195 126 |
| Relative Sensi- Magnetic Livity for Moment # Squal Number of Nuclei of Nuclei w | Spin I NMR Frequ in MHs for in MHs for kilogauss fic kilogauss fic kilogauss fic kilogauss fic kilogauss fic kilogauss fic kilogauss Astural ficus fical f | 3/2 10.667 50.54 7.86x10.* 1.25 2.0900 8 N | 5 2.005 — 4.208x10 - 0.439 1.37 94 Ab 3/2 11.498 49.46 9.85x10 ⁻² 1.35 2.2626 8 N | 5 2.479 — 7.90x10 ⁻² 2.33 (+11.526 95 Ab (- 9/2 1.638 11.55 1.88x10 ⁻³ 1.27 -0.9671 96 N 9/2 1.634 — 2.08x10 ⁻³ 1.37 -1.001 98 0 | 3/2 10.4 7.32x10 ⁻² 1.22 2.05 99 5.229 6.50x10 ⁻³ 1.10 99 | 5/2 4.108 72.15 1.05x10 ⁻² 1.13 1.3482 100 N | 2 6.44 — 2.77x10 ⁻² 1.21 —1.69 102 Ab 32 13.231 27.85 0.175 1.64 2.741 103 N 0.13 0.72 1.245 7.09 securing 1.43 —1.0803 66 N 0.2 | 1/2 1.0859 100 1.18810 ⁻⁴ 4.90x10 ⁻² -0.1862 47 N - 2.44x10 ⁻⁴ 1.16 -1.62 105 Ab -0.16 | 1/2 2.49 1.99x10 ⁻⁴ 5.84x10 ⁻² 0.163 60 Ab 5/2 3.97249 111.23 9.48x10 ⁻³ 1.09 1.3024 106 N | 5/2 2,0407 100 0,452 8,077 0,150 0,097 6,012 8,57 2,57 15,7 15,72 3,233,10° 0,750 0,097 45 N 1.1 5,72 2,532 9,46 3,433,10° 0,77 -0,2289 45 N 1.1 0,7 0,7 0,7 0,7 0,7 0,7 0,7 0,7 0,7 0,7 | 9/2 8.8839 — 0.5170 1.49 2.84 112 Mo 5/2 2.1 17.07 1.41810° 0.576 -0.69 113 O | 1/2 1.3401 100 3.11x10 ⁻⁵ 3.15x10 ⁻² -0.08790 43 | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | 1/2 1.54 — 4.73x10 ⁻⁵ 3.62x10 ⁻⁷ 0.101 117 1/2 1.7229 51.82 6.62x10 ⁻⁵ 4.05x10 ⁻⁷ -0.11301 47 | 32.0 — 1.13 2.01 4.2 110 1.0007 4.818 101v10 ⁻⁴ 4 46x10 ⁻² -0.19992 47 | 6 4.587 - 6.87x10-1 5.99 8.587 120 | 2 2.21 — 1.40x10 5.10x10 0.145 121 2 2 0.00x10 6.0545 122 122 122 122 122 122 122 122 122 12 | 2.529 — 2.44x10 ⁻³ 0.693 —0.8293 124 0 0.8 | 12.75 9.54x10-* 0.212 -0.5922 | 9.445 12.26 1.09x10 ⁻² 0.222 -0.6195 126 |
| Relative Sensi- Magnetic Livity for Moment # Squal Number of Nuclei of Nuclei w | Spin I NMR Frequ in MHs for in MHs for kilogauss fic kilogauss fic kilogauss fic kilogauss fic kilogauss fic kilogauss fic kilogauss Astural ficus fical f | 79 3/2 19.667 50.54 7.86x10 ⁻¹ 1.25 2.0900 8 N | 80° 5 2.2828 — 2.083310 • 0.249 1.317 94 Ab 81° 3/2 11.498 49.46 9.85310 1.35 2.2828 8 N | 82* 5 2479 — 7.90x10 ⁻³ 2.33 (+)1.638 95 Ab (- 83 9/2 1.638 11.55 1.88x10 ⁻³ 1.27 -0.967 N 85* 9/2 1.60x6 — 2.08x10 ⁻³ 1.31 -1.001 98 0 | 81° 3/2 10.4 | 84° 2 5.38 — 1.3810° 0.45 - 1.18 99 Ab 85 5/2 4.1108 72.15 1.05x10° 1.13 1.3482 100 N | 86* 2 6.44 2,77x10"* 1.21 -1.69 102 Ab 87 3/2 13.831 27.85 0.175 1.64 2.7414 103 N 0.13 87 0/2 1.040 7.70 5.00410"* 143 -1.0903 66 N 0.2 | 89 1/2 1.0839 100 1.08410 ⁻⁴ 4.90710 ⁻⁴ -0.13682 47 N 90 2 2.0839 100 2.44x10 ⁻⁴ 1.16 -1.62 105 Ab -0.16 | 91* 1/2 2.49 — 1.99x10 ⁻⁴ 5.84x10 ⁻² 0.163 60 Ab — 91 5/2 3.97249 11.23 9.83x10 ⁻¹ 1.09 —1.3024 106 N | 93 9/2 10.407 100 -0.382 507 0.082 107 0.02 95 5/2 2.832 9/46 3.43x10 ⁻¹ 0.776 0.993 45 N 1.1 5/2 2.832 9.46 3.43x10 ⁻¹ 0.776 0.993 45 N 1.1 | 99 9/2 1.44 12.72 1.95x10 ⁻⁴ 0.169 -0.294 112 Mo 101 15/2 2.1 17.07 1.41x10 ⁻⁴ 0.576 -0.69 113 0 | 103 1/2 1.3401 100 3.11x10 ⁻⁵ 3.15x10 ⁻² -0.08790 43 | 106 5/2 1:95 22.23 1.12x,10 ⁻⁴ 0.534 -0.639 115 104 5 6.1 - 0.118 5.73 4.0 116 104 2 14.0 - 0.118 2.73 7.1 116 | 105° 1/2 1.54 — 4.73x10"s 3.62x10"s 0.101 117 | 108" 1 32.0 — 1.13 2.01 4.2 119 100 100 100 100 100 100 100 100 100 | 1100 6 4.857 — 6.873.00 3.857 120 | 111 1/2 2.21 — 1.40x10-8.19x10-6.145 121 112 2 0.2077 — 9.00x10-7 3.90x10-7 0.0545 122 | 107° 5/2 1.879 — 1.00x10° 0.515 — 0.6162 1.00 0.8 1.00 0. | 12.75 9.54x10-* 0.212 -0.5922 | 9.445 12.26 1.09x10 ⁻² 0.222 -0.6195 126 |
| Relative Sensi- Magnetic Livity for Moment # Squal Number of Nuclei of Nuclei w | I migs The equal to the property of the prope | *Br 79 3/2 19.667 50.54 7.96x10 ⁺ 11.25 2.0910 8 N | Br 80, 5 2.008 — 4.20x10* 0.240 0.511 94 Ab *Br 81 3/2 11.498 49.46 9.85x10* 1.35 2.2626 8 N | Br 82° 5 2479 — 7.90x10° 2.33 (+)1.626 95 Ab (- *Kr 83 9/2 1.638 11.55 1.88x10° 1.27 — 0.9671 96 N Kr 85° 9/2 1.638 — 2.08x10° 1.31 —1.001 98 0 | Rb 81* 3/2 10.4 7.32x10^2 1.22 2.05 99 Rb 822 5.229 6.0x10^2 2.15 1.50 99 Rb 620x10^2 2.15 1.50 99 | Rb 84° 2 5.03 — 1.28x10° 1.18° 1.32° 99 Ab *Rb 85 5/2 4.1108 72.15 1.05x10° 1.13 1.3482 100 N | Rb 86* 2 6.44 — 2.77x10** 1.21 -1.69 102 Ab 0.13 -Rb 87 3/2 13.931 27.85 0.175 1.64 2.7414 103 N 0.13 -6, 97 0/2 13.937 772 9.804210** 1.43 -1.0093 fig. N 0.2 | *Y 89 1/2 2.0859 100 1.18x10 ⁻⁴ 4.90x10 ⁻² -0.3362 47 N | Y 91° 1/2 2.49 — 1.99x10"4 5.84x10"2 0.163 60 Ab — 2r 91 5/2 3.97249 11.23 9.48x10"1 1.09 1.30284 106 N | 93 9/2 10.407 100 -0.382 507 0.082 107 0.02 95 5/2 2.832 9/46 3.43x10 ⁻¹ 0.776 0.993 45 N 1.1 5/2 2.832 9.46 3.43x10 ⁻¹ 0.776 0.993 45 N 1.1 | FIG. 99° 8/2 8.8830 — 0.50° 6.43 5.057, 110 A 0.50 Ru 99 3/2 1.44 12.72 1.95x10⁴ 0.156 -0.284 112 Mo Ru 101 5/2 2.1 17.07 1.41x10⁴ 0.576 -0.09 113 O | •Rh 103 1/2 1.3401 100 3.11x10 ⁻⁵ 3.15x10 ⁻⁷ -0.08790 43 | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | 105° 1/2 1.54 — 4.73x10"s 3.62x10"s 0.101 117 | 108" 1 32.0 — 1.13 2.01 4.2 119 100 100 100 100 100 100 100 100 100 | 1100 6 4.857 — 6.873.00 3.857 120 | 111 1/2 2.21 — 1.40x10-8.19x10-6.145 121 112 2 0.2077 — 9.00x10-7 3.90x10-7 0.0545 122 | 1/2 2.859 — 2.44x10 ⁻³ 0.693 -0.8293 124 0 0.8 | 12.75 9.54x10-* 0.212 -0.5922 | 9.445 12.26 1.09x10 ⁻² 0.222 -0.6195 126 |