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A TABLE OF NUCLEAR
MOMENT DATA

EDITED BY

Harold E. Walchli

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A TABLE OF NUCLEAR MOMENT DATA

Harold E. Walchli, Editor

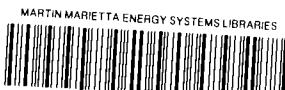
April 1, 1953

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ABSTRACT

A Table of Nuclear Moment Data has been compiled and is divided into three sections. The first section lists for each nucleus: the measured frequency ratio, the compounds used, the method of measurement, the resonance frequency relative to that for the proton, and a value for the magnetic moment without diamagnetic correction. The second section provides a tabulation of the weighted magnetic moments with the calculated diamagnetic corrections, and a table of the standard frequency ratios used for calculations in the first section. A table of the moment ratios is also given. The third section of the table is devoted to information concerning the chemical shifts measured for various elements. Several useful charts, graphs and a complete reference bibliography have been included.

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A TABLE OF NUCLEAR MOMENT DATA

Introduction

During the past several years a great many measurements have been made for the purpose of determining nuclear magnetic dipole moments. Several tables have been compiled giving values for the respective magnetic moments, but in each case the tabulation has become obsolete because of newer and better measurements. With better equipment obtainable and the increasing availability of enriched stable and radioactive isotopes such tabulation of specific nuclear magnetic data is becoming more and more important. The large number of articles being published makes a complete literature search extremely time consuming when information on several different nuclei is required.

This report has the primary purpose of reporting the information "as previously published" and eliminates a best value tabulation except for purposes of comparison. In past tabulations of nuclear moments, the authors have in most instances chosen to use only a "best value" listing with the exception of the tables of H. L. Poss, BNL-26 (T-10).

The present tabulation originated as an expansion of a "Table of Nuclear Moments," by J. E. Mack (MA 50). In so far as possible, his reference nomenclature has been retained with other additions for the more recent data.

The Table of Nuclear Moment Data has been divided into three parts. The first part consists of the tabulation of the nuclear moment data. The second part includes a table of weighted nuclear magnetic moments and standard frequency data used in calculations for Part I. The third section is concerned with the collecting of information on chemical effects in nuclear magnetic shielding. During the preparation of this tabulation, it is likely that errors have occurred. The author requests that any errors found be called to his attention. In addition, the author will be pleased to receive advance or current information on items suitable for inclusion in the supplementary issues.

PART 1. THE TABLE OF NUCLEAR MOMENT DATA

A discussion of Table 1.1

The columns of the table consist of the following:

1. N, the neutron number
2. Z, the proton number or atomic number
3. Chemical symbol
4. A=N+Z, the atomic mass integer
5. I, the nuclear spin quantum number (and reference)
6. μ in nuclear magnetons ($eh/2M_pC$)
7. Q, the quadrupole moment
8. The reference symbol for the method employed in measurement
9. The reference standard and its mass number
10. The ratio of frequency of resonance for the isotope to the frequency of resonance for the reference listed in column 9
11. The tolerance and its reference symbol
12. The compound or sample used for measurement
13. The literature reference symbol
14. The frequency ratio for the isotope to that of the proton ($f/f(H)$)

Quantities that are considered to be doubtful, in question, or superseded by new data are enclosed in brackets.* A detailed interpretation of each of the 8 columns requiring further description follows:

Column 4. A = N + Z

A place has been included in the tabulation for all known odd mass elements and also for the several odd-odd isotopes. All even-even isotopes have been omitted because their magnetic moment or spin is assumed to be zero. Some long lived radioactive isotopes have been included.

Column 5. The Spin Quantum Number

The value of spin reported is that given in MA 50 except for those cases in which a change has occurred or a new value reported. In these cases, the reference is noted by a bracketed symbol directly following the spin value. These references follow the same notation system as in column 13 and are listed in the table of references. Doubtful values of I are enclosed in parenthesis.

*See explanation of column 5 for changes for the case of spin.

Column 6. The Magnetic Moment μ

During the past three or four years several measurements have been made giving a precise value for the proton moment in nuclear magnetons and reciprocal gauss-sec. Mack in his table has chosen the value of 2.79255 nm for that of the proton (with diamagnetic correction). Since that time, however, more accurate results have been reported for the proton magnetic dipole moment. The calculated value for each nuclear magnetic moment is dependent upon the value chosen for the proton moment. Because measurements are now being made that have a precision greater than that of the known diamagnetic correction (especially for the higher Z atoms), a decision was made to tabulate in terms of the uncorrected moment of the proton. For those who wish to compute a diamagnetically corrected value for various nuclei a table of Internal Diamagnetic Corrections for Neutral Atoms as determined by W. C. Dickinson (DN 50) is included as Table 3.1. Additional references covering magnetic shielding and corrections will be found in Part 3 Magnetic Shielding.

For the purpose of our calculations we have chosen the magnetic moment of the proton without diamagnetic correction to be exactly 2.7926700... nm.

A further discussion of the choice of values selected is found on page 78. Since the values of the calculated moments depend upon the μ_p value they can be known to no greater absolute accuracy than μ_p . The tolerances of the calculated moments (where given) do not include the error in the μ_p value but only that for the measurement(s) under consideration. In those cases where the calculation of the moment depends upon the product of two measured ratios, the stated moment includes the weighted errors of both ratios. The methods of nuclear induction and absorption appear to give data of higher precision than the hyperfine structure method. Therefore, only data of significance determined by spectroscopic means are included. In some of these cases the original μ is given and because of insufficient data this has not been changed to our "standard μ_p " basis. In most cases neither this fact nor the diamagnetic correction are very significant since the stated deviations are very broad. However, in order that this listing might be complete, reference to early work is given in column 13 where an asterisk by a designation indicates the work to be of historic or preliminary worth. No data are listed for most of these references.

Column 8. Methods of Measurement

A listing is given in column 8 of the method used in obtaining data given for each reference. For the sake of consistency the symbolism of

Mack has been retained for this notation and, in addition, other notations have been added. The following is a list of notations used for the various methods:

- A Atomic beam magnetic resonance
- B Band spectra
- C Raman spectra
- H Specific heat
- M Molecular beam magnetic resonance
- N Nuclear scattering
- O Ortho-para conversion
- P Polarization of resonance radiation
- R Nuclear resonance absorption or induction
- S Hyperfine structure in line spectra
- W Microwave absorption
- Z Zero moment or atomic beam deflection
- G Omegatron
- DC Decelerated cyclotron
- Q Direct quadrupole transition
- X Other methods (such as paramagnetic resonance)
- T Theoretical calculations or predictions
- L Nuclear alignment
- γ Angular correlation

Column 10. Frequency Ratio Tabulation

This column lists the published resonance frequency ratio at a fixed magnetic field for the isotope under observation to that of some other element that has been designated as the reference standard. This reference standard is listed in column 9 by chemical symbol and mass number N. In so far as possible, the frequency ratio has been recorded as reported; however, in a few instances it has been more convenient to list a reciprocal value. For those nuclides where a frequency ratio has not been reported but a significant "g" ratio has been given, a small gr precedes the value and the reference nuclide is given in column 9. For those cases where only a "g" factor is reported a numeral 1 is found in column 9 and a small g precedes the value. A similar method using μ and μ_r has been adopted where only the magnetic moment has been reported.

Column 11. Errors and Tolerances

The tolerances given are those as reported by the individual authors. In columns 6 and 14 the numbers enclosed in parenthesis following a value give the tolerance (\pm) for the last two digits stated in the value.

As is noted, a great many different forms of tolerances are reported. Some authors choose to use an estimate of the combined known sources of error, while others report a mean deviation, probable error, or a standard deviation. The results of this erratic means of designating the error makes the problem of determining a weighted average extremely difficult. It has been felt that all information concerning the reported deviation should be readily available for use in comparing results of various measurements. Column 11 has therefore been included to supply this information. Where the deviation is defined by the author this has been included with a letter symbol following the deviation. The following is a list of the symbols used for the various designations:

MD Arithmetic average or mean deviation

PE Probable error of the mean based on $0.6745 [\Sigma X^2 / n(n-1)]^{1/2}$

EE Estimated error, based on equipment parameters

σ Standard deviation

XD Maximum deviation

In addition, some authors have included further information on the number of measurements made, etc. To symbolize this information a number followed by an "s" following the tolerance symbol will denote the number of sets of data, a number followed by an "m" following the tolerance data will indicate the number of measurements made per set. Thus a designation $\pm 0.0033 \text{ PE } (5s)(4m)$ would be interpreted as the probable error of the mean of five sets, each containing 4 independent measurements. In some cases several tolerance figures will be given for each value.

A complete discussion of the correction factors to be considered in interpreting these data is given in MA 50 and LM 51-2 and is not repeated here.

Column 12. Chemical Information

It is well known that chemical effects play an important part in determining the value of the measured magnetic moment. As much information as conveniently possible has therefore been included when given by the author. Numerous procedures have been followed by the various laboratories in making measurements. Some have chosen to use separate samples and interchange them during measurements, some have used mixed samples, others have sealed off one sample and submerged it in the other sample, while still others have used two different instruments to measure the ratio

in different portions of the magnetic field and then correct for this by various means. Also, Dickinson has pointed out effects of sample shape and composition (DN 51). It would indeed be useful to have all of this information available for listing with each experiment datum; however, it is impossible to determine the exact procedure from the literature in most cases and we have therefore been forced to omit this feature. The following notation concerning the samples is used in column 12:

1. All samples were aqueous solutions except where noted.
2. A + sign between two chemicals means they were mixed in the same solution.
3. Where separate samples were used the word and appears between the various compounds.

A notation such as NaCl sat. + .1m MnSO₄ + D₂O and 1N HNO₃ would be interpreted as a saturated aqueous solution of sodium chloride containing .1 molar manganese sulphate as a magnetic catalyst and some deuterium oxide; a second sample containing 1 normal nitric acid was used for the other element reference source.

Where measurements have indicated different results for various compounds of an element, in general only that compound exhibiting the least paramagnetic shielding has been included in the table of Part 1. The other compounds will be found in the listings of Part 3. For purposes of determining the compound exhibiting the least paramagnetic shielding it has been assumed that the diamagnetic correction will be the same for a nucleus regardless of compound. Ramsey and others have pointed out that separation of the chemical effects from the diamagnetic effects is artificial. (See Part 3). However, in Table 1.1, lacking a more definite method, the assumption has been made that the diamagnetic correction is the same for all compounds of a particular nucleus and that the resonance appearing at the highest value of externally applied field (frequency constant) or lowest frequency (field constant) exhibits the least paramagnetic shielding.

Because chemical effects are so important, a complete section has been assigned for their discussion and tabulation. This will be found in Part 3.

Column 14. The Nuclide-to-Proton Resonance Frequency Ratio

A convenient method for comparing the various measured frequency ratios is to compare all resonance frequencies with that of the proton at the same value of magnetic field. To do this, a number of standard frequency ratios were required. The selection of these particular standard

values may make invalid a precise comparison of the calculated tabulated $f/f(H)$ ratio versus the directly measured values, but does give a comparative check on the results from different laboratories and an indication of possible systematic errors. The standards have been chosen by calculating a weighted value based on independent direct measurements. This direct measurement has sometimes been modified by a second weighting where the indirectly determined $f/f(H)$ ratios were considered. This has been used especially for those cases where the combined errors in the indirectly computed ratios are of the same order of magnitude as the direct measurements or where no direct measurement has been reported. DuMond and Cohen in the method of least squares determinations have shown nuclear resonance measurements to fall into specific accuracy groupings. In keeping with their findings all measurements having deviations in excess of reasonable limits based on presently available accuracies have not been included in the $f/f(H)$ weighted values. In those cases where probable error has been given for all measurements this has been used in determining the weighting by the usual means; in other cases the published tolerances were used as if they were the probable error. The resulting specified tolerance is the probable error of the mean based on a 95 per cent confidence level. Further data are given in Part 2, page 65. The final results are at best an approximation but the effects of arithmetic redundancy have been somewhat reduced. A list of the standards used with their calculated tolerances is found as Table 2.1 of Part 2.

Column 7. Quadrupole Moment

Since the tabulation of nuclear quadrupole data would require a complete literature search it was not feasible to include this information at the present time. However, the reader is referred to the publication of Mack (MA 50) for this information on data available up to the year 1950. A place has been provided for individuals to insert published measurements in a column designated as Q of Table 1.1.

TABLE 1.1

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
N	Z	Atom	A	I	Magnetic Moment	Q	Meth.	Std.	$\frac{f(x)}{f(Std.)}$	Tolerance	Chemical Information	Ref.	$\frac{f(x)}{f(H)}$
0	0	e	0		$[1.001\ 146\ (12)\mu_0]$		A	$\frac{g_s^a}{g_p(\text{free})}$	658.208 7	$\pm .000\ 6$		KB 52	
								$\frac{g_s^a}{g_p(\text{oil})}$	658.228 8	$\pm .000\ 6$	Spherical sample mineral oil		
					$(1.001\ 145\ 4)\mu_0$		T				KA 50		
1	0	n	$\frac{1}{2}$										
					-1.935 (2)		DC				AC 40		
					1.912 4 (11)		R	H ¹	.684 79	$\pm .000\ 2\ MD$.000 4 EE	n and H ₂ O	AQ 47	.68479 (40)
					1.912 98 (9)		R	H ¹	.685 001	$\pm .000\ 03\ (10m)$		BL 48	.685001 (30)
					Sign negative		R		(Sign only)			RV 49	

a. See original reference for meaning.

N	Z	Atom	A	I	Magnetic Moment	Q	Meth.	Factor		Published Ratios	Chemical Information	Ref.
									Measured			
0	1	H	1	$\frac{1}{2}$	+2.792 88 (14)	M		1	$15.210\ 3 \times 10^{-4}$ B.M. $\pm .005\%$ EE		NaOH	TA 49
								g_H	$30.420\ 6 \times 10^{-4} \pm .005\%$			
					2.792 78 (40)	M		$\frac{\omega_e^a}{\omega_p}$	657.475 $\pm .008$		n, mineral oil	GD 49
								1	$(15.210 \pm .000\ 2) \times 10^{-4}$ B.M.			GD 51
					2.792 74 (7)	G		γ_p	$2.675\ 23 \pm .000\ 03$ AD .000 06 EE $g^{-1}\ sec^{-1}$		$H_2O +$ Ferric Salt	TH 50-2
					2.792 79 (7)	G		γ_p	$2.675\ 30^5 \pm .000\ 06$ $g^{-1}\ sec^{-1}$ corrected (10s)	" " "		TH 50
					2.792 68 ⁵ (6)	G		$\frac{\gamma_n^a}{\gamma_c}$	$2.792\ 685 \pm .000\ 025$ AD .000 06 EE (45m)		H^+ and oil	SO 51
					2.792 45 (20)	R		μ	2.792 45 $\pm .000\ 2$		H_2O and n	BL 50
					2.792 4 ² (2)	DC		μ	2.792 4 ² $\pm .000\ 2$		$H_2O + .02m$ $MnSO_4$	JR 51
					2.792 73 (30)	R		γ_p	$(2.675\ 25 \pm .000\ 20) \times 10^{-4}$ $g^{-1}\ sec^{-1}$		RaC I-F Lines	LM 51-2

*TH 49

*HP 49

*SO 50

a. See original reference for meaning

TABLE 1.1 (Cont.)

<u>N</u>	<u>Z</u>	<u>Atom</u>	<u>A</u>	<u>I</u>	<u>Magnetic Moment</u>	<u>Q</u>	<u>Meth.</u>	<u>Std.</u>	<u>$f(x)$</u> <u>$f(Std.)$</u>	<u>Tolerance</u>	<u>Chemical Information</u>	<u>Ref.</u>	<u>$f(x)$</u> <u>$f(H)$</u>
1	1	H	2	1									
					+.857 4 (3)		R	H ¹	.153 51	± .000 05 PE	D ₂ O and n	AQ 47	.15351 (5)
					.857 384 8 (66)		R	H ¹	.153 506 3	± .000 001	.1 molar MnSO ₄ in + 50% D ₂ O	BL 47-3	.1535063 (10)
					.857 354 (42)		R	H ¹	.153 500 8 ⁵	± .000 007 ⁵	85% D ₂ O	RU 47	.1535008 (75)
					.857 408 (14)		R	H ¹	.153 510 5	± .000 002 ⁵	liquid H ₂ ¹ , liquid D ²	BI 47	.1535105 (25)
					.857 4 (28)			H ¹	.153 515	± .000 5		ML 41	.15352 (50)
					[.857 42 (30)]		R	H ¹	(used BL 47-3 values)			BL 48	.1535063 (10)
					.857 63 (28)		R	H ¹	.153 55	± .000 05	95% D ₂ O	ZI 49	.15355 (5)
					.857 382 4 (48)		R	H ¹	.153 505 8 ⁵	± .000 000 8 ⁵	H ₂ O + D ₂ O	WJ 49	.15350585 (85)
					.857 382 4 (42)		R	H ¹	.153 505 8 ⁵	± .000 000 7 ⁵	D ₂ O	LV 50	.15350585 (75)
					.857 387 0 (14)		R	H ¹	.153 506 68 ⁵	± .000 000 25 (13m)	D ₂ O and H ₂ O	LM 50	.15350668 (25)
					.857 387 0 (84)		R	H ¹	.153 506 68 ⁵	± .000 000 15	D ₂ O and H ₂ O	LM 51	.153506685 (150)
					.857 387 0 (14)		R	H ¹	.153 506 68	± .000 000 04 PE (15s) .000 000 25 EE .000 000 33 XD	D ₂ O and H ₂ O	LM 51-2	.15350668 (25)
					.857 383 65 (34)		R	H ¹	.153 506 08	± .000 000 02 PE .000 000 06 EE	H ₂ O + D ₂ O	SR 51	.15350608 (6)
					.857 383 90 (28)		R	H ¹	.153 506 125	± .000 000 05	H ₂ + D ₂	SR 51	.153506125 (50)
					.857 381 8 (66)		M	H ¹	.153 505 7	± .000 001 2 $\mu r = 3.257 207$	HD and D ₂	BY 52	.1535057 (12)
					.857 383 738 (42)		R	H ¹	.153 506 096	± .000 000 0075	H-D Gas	WJ 53 ²	.153506096 (8)

TABLE 1,1 (Cont.)

N	Z	Atom	A	I	Magnetic Moment	Q	Meth.	Std.	$\frac{f(x)}{f(Std.)}$	Tolerance	Chemical Information	Ref.	$\frac{f(x)}{f(H)}$
2	1	H	3	$\frac{1}{2}$									
					+2.978 83 (28)		R	H ¹	1.066 66	$\pm .000\ 10$	H ₂ O + Fe(NO ₃) ₂	AN 47	1.06666 (10)
					2.978 762 (28)		R	H ¹	1.066 636	$\pm .000\ 010\ (21s)$	50% H ¹ + 50% H ³ in .1m MnSO ₄	BL 47-2	1.066636 (10)
1	2	He	3	$\frac{1}{2}$									
					(-)2.127 419 (7)		R	H ¹	.761 786 6	$\pm .000\ 001\ 2\ (4\sigma)$	He ³ gas, H ₂ gas	AN 48	.7617866 (12)
					2.131 (3)		R	H ¹	.763	$\pm .01$	He ³ gas + O gas under pressure	AN 48-2	.763 (1)
3	3	Li	6	1									
					+ .821 924 (28)		A	Li ⁷ gr =	.378 653	$\pm .000\ 007$		KU 49-4	.147157 ⁴ (5)
					.821 933 (23)		R	Li ⁷ gr =	.378 657	$\pm .000\ 001^5$	LiCl aqueous	WA 51	.147159 (4 ⁵)
					.821 914 1 (62)		R	D	.958 629	$\pm .000\ 008\ PE\ (7m)$.000 066 XD .000 020 EE	LiCl + D ₂ O + .1m MnSO ₄	WL 52-5	.1471555 (30)
					.821 934 (17)		R	Li ⁷	.378 657 25	$\pm .000\ 000\ 72\ (18m)$	LiCl + .1m CrCl ₃	AD 51-2	.1471592 (31)

*ML 39-1

TABLE 1.1 (Cont.)

<u>N</u>	<u>Z</u>	<u>Atom</u>	<u>A</u>	<u>I</u>	<u>Magnetic Moment</u>	<u>Q</u>	<u>Meth.</u>	<u>Std.</u>	<u>$\frac{f(x)}{f(Std.)}$</u>	<u>Tolerance</u>	<u>Chemical Information</u>	<u>Ref.</u>	<u>$\frac{f(x)}{f(H)}$</u>
4	3	Li	7	$\frac{3}{2}$									
					+3.256 2 (11)		M	H ¹	gr = .388 66	$\pm .000\ 12^5$		ML 41	.38866 (12)
					3.255 91 (31)		R	H ¹	.388 625	$\pm .000\ 038$		BI 49	.388625 (38)
					3.255 80 (11)		R	H ¹	.388 613	$\pm .000\ 013$ XE (6s)	LiNO ₃ aqueous	SN 49	.388613 (13)
					3.22 (2)		R	H ¹	gr = .385	$\pm .003$		BP 46	.385 (3)
					3.255 8 (2)		R	H ¹	.388 62	$\pm .000\ 02$		ZI 49	.38862 (2)
					3.255 904 (9)		R	H ¹	.388 634 9	$\pm .000\ 001\ 0$	LiNO ₃	LM 51	.3886349 (10)
					3.255 982 (9)		R	H ¹	.388 634 1	$\pm .000\ 000\ 2$ PE .000 001 8 MD .000 001 0 EE	LiNO ₃	LM 51-2	.3886341 (10)
					3.256 01 (9)		R	H ¹	.388 637	$\pm .000\ 010$	LiCl + .1m MnSO ₄ aqueous	KO 52	.388637 (10)
					3.256 026 (42)		R	Na ²³	1.469 236	$\pm .000\ 007$ PE (7m) .000 062 XD .000 020 EE	LiCl + .1m MnSO ₄ and NaCl aqueous	WL 52-5	.3886396 (50)

*GS 32

*FP 35

TABLE 1.1 (Cont.)

<u>N</u>	<u>Z</u>	<u>Atom</u>	<u>A</u>	<u>I</u>	<u>Magnetic Moment</u>	<u>Q</u>	<u>Meth.</u>	<u>Std.</u>	<u>$\frac{f(x)}{f(Std.)}$</u>	<u>Tolerance</u>	<u>Chemical Information</u>	<u>Ref.</u>	<u>$\frac{f(x)}{f(H)}$</u>
5	4	Be	9	$\frac{3}{2}$	[SP 51, HT 51, ME 52]								
					-1.175 8 (6)		R	H ¹	.14034	$\pm .000\ 07$ MD	BeCl ₂ aqueous	CH 49	.14034 (7)
					1.175		M	1	g = .783	$\pm .003$	NaF•BeF ₂	KU 39-1	.1402 (6)
					1.177 267 ⁵ (17)		R	H ¹	.140 518 7	$\pm .000\ 002$ MD (10s)	BeF ₂ aqueous	DN 49	.1405187 (20)
					1.177 37 (9)		R	D ²	.915 475	$\pm .000\ 07$ PE (8s)	BeCl ₂ + D ₂ O + NiCl ₂	SW 51	.140531 (11)
					Negative		R		Sign only			AY 51-2	
5	5	B	10	3									
					+1.791 (9)		M					ML 39	
					+ .597 (3) (I = 1)								
					1.800 3 (6)		R	B ¹¹	.334 88	$\pm .000\ 10$		BI 49	.10744 (3)
					1.800 6		R				aqueous Na ₂ B ₂ O ₄	TI 51	
					1.800 67 (17)		R	D ²	.700 065	$\pm .000\ 07$ EE ($\geq 10m$)	Na ₂ B ₂ O ₄ and D ₂ O + NiCl ₂	TI 52-2	.107464 (10)
					1.800 35 (17)		R	Rb ⁸⁵	1.112 82	$\pm .000\ 05$ EE ($\geq 10m$)		TI 52-2	.107445 (10)

TABLE 1.1 (Cont.)

<u>N</u>	<u>Z</u>	<u>Atom</u>	<u>A</u>	<u>I</u>	<u>Magnetic Moment</u>	<u>Q</u>	<u>Meth.</u>	<u>Std.</u>	<u>f(x)</u>	<u>f(Std.)</u>	<u>Tolerance</u>	<u>Chemical Information</u>	<u>Ref.</u>	<u>f(x)</u>
														<u>f(H)</u>
6	5	B	11	$\frac{3}{2}$	+ 2.682 (8)		M						ML 39	
					2.688 1 (9)	R	H ¹	.320 85		± .000 10			BI 49	.32085 (10)
					2.687 3 (8)	R	H ¹	.320 76		± .000 09	Na ₂ B ₂ O ₄ aq.		ZI 49	.32076 (9)
					2.687 89 (4)	R	H ¹	.320 827		± .000 004	K ₂ B ₂ O ₄ (H ₃ BO ₃ + KOH) super sat. soln.	AE 49	.320827 (4)	
					2.687 95 (8)	R	H ¹	.320 834		± .000 009 (7m)	BF ³ etherate		AD 49	.320834 (9)
					2.688 19 (6)	R	Li ⁷	.825 615		± .000 04 PE (8s)	Na ₂ B ₂ O ₄ and LiC ₂ H ₃ O ₂ ⁺ Mn(C ₂ H ₃ O ₂) ₂		SW 51	.320862 (7)
					2.687 979 (17)	R	H ¹	.320 837 4		± .000 002 0	Na ₂ B ₂ O ₄ K ₂ B ₂ O ₄		LM 51	.3208374 (20)
					2.687 985 (7)	R	H ¹	.320 838 1		± .000 000 1 PE ± .000 001 4 XD ± .000 000 8 EE	K ₂ B ₂ O ₄ sat. aq. and H ₂ O	LM 51-2	.3208381 (8)	
7	6	C	13	$\frac{1}{2}$	+ .701	M	1	g = 1.402		± .004			HH 41	.2510 (7)
					.702 16 (14)	R	H ¹	.251 43		± .000 005 PE ± .000 05 EE	56% C ¹³ methyl Iodide and mineral oil	PH 49	.25143 (5)	

TABLE 1.1 (Cont.)

<u>N</u>	<u>Z</u>	<u>Atom</u>	<u>A</u>	<u>I</u>	<u>Magnetic Moment</u>	<u>Q</u>	<u>Meth.</u>	<u>Std.</u>	<u>$f(x)$</u>	<u>$f(Std.)$</u>	<u>Tolerance</u>	<u>Chemical Information</u>	<u>Ref.</u>	<u>$f(x)$</u>
													<u>$f(H)$</u>	
7	7	N	14	1										
					+ .402		M						KU 39-2	
					.403 57 (4)		R	D ²		.470 70	± .000 05	.6m MnSO ₄ aq. sol. 85% D ₂ O and HNO ₃	PR 50 PR 51	.072255 (7)
					.403 57 (2 ³)		R	Rb ⁸⁵		.748 37	± .000 04 EE ($\geq 10m$)	HNO ₃ and Rb Cl aq.	TI 52-2	.072257 (4)
8	7	N	15	$\frac{1}{2}$										
					- .280		M	1	g =	.560	± .006	50% N ¹⁵ Gas	ZA 40	.997 (10)
					.282 95 (3)		R	D ²		.660 04	± .000 06	5 ml. liq. NH ₃ + 1.18 g NH ₄ NO ₃ + 1.25 g Cr(NO ₃) ₃ • 9H ₂ O	PR 50	.101320 (10)
					.283 03 (4)		R	N ¹⁴		1.402 6	± .000 1	7.5% N ¹⁵ and PR 50 (above sample)	PR 51	.101346 (15)
					.283 05 (4)		R	N ¹⁴		1.402 7	± .000 1	6.2 mol. aq. NaNO ₃ (31% N ¹⁵) + .1m MnSO ₄	PR 51	.101353 (15)
9	8	O	17	$\frac{5}{2}$	[AY 51, GC 52]									
					-1.892 96 (9)		R	D ²		.883 13	± .000 04	O ¹⁷ in H ₂ O + D ² in D ₂ O	AY 51	.135566 (6)

TABLE 1.1 (Cont.)

TABLE 1.1 (Cont.)

<u>N</u>	<u>Z</u>	<u>Atom</u>	<u>A</u>	<u>I</u>	<u>Magnetic Moment</u>	<u>Q</u>	<u>Meth.</u>	<u>Std.</u>	<u>$f(x)$</u>	<u>Tolerance</u>	<u>Chemical Information</u>	<u>Ref.</u>	<u>$\frac{f(x)}{f(H)}$</u>
11	11	Na	22	3									
					+1.746 (3)		A		based on $\mu_{Na^{23}}$ Phys. Rev., 58, 438 (1940)			DI 48	.1042(3)
					1.745 8 (22)		A					DI 49-2	.10419 (14)
12	11	Na	23	³ ₂									
					+2.214 7		M	1	$g = 1.476\ 5$			ML 41	.26435
					2.216 0 (6)		R	H ¹	.264 50	$\pm .000\ 03$	NaI or NaCl	BI 49	.26450 (3)
					2.216 3 (6)		R	H ¹	.264 54	$\pm .000\ 07$	NaAsO ₂ , also NaI, NaBr, Na ₂ B ₂ O ₄	ZI 49	.26454 (7)
					2.216 15 (14)		R	Sc ⁴⁵	1.088 83	$\pm .000\ 05$ PE (8s)	Na ₂ B ₂ O ₄ and ScCl ₃	SW 51	.264520 (16)
					2.215 93 (14)		R	Sc ⁴⁵	1.088 72	$\pm .000\ 06$ PE (8s)	NaBr and ScCl ₃	SW 51	.264494 (17)
					2.216 137 (7)		R	H ¹	.264 518 4	$\pm .000\ 001\ 5$	NaBr aq and Na ₂ B ₂ O ₄ aq	LM 51	.2645184 (15)
					2.216 136 (4)		R	H ¹	.264 518 2	$\pm .000\ 000\ 1$ PE .000 001 1 XD .000 000 7 EE	NaBr and Na ₂ B ₂ O ₄	LM 51-2	.2645182 (7)
					2.216 10 (8)		R	H ¹	.264 514	$\pm .000\ 009$	NaI + .1m MnSO ₄	KO 52	.264514 (9)
												*FP 35	
												*KU 39-2	
												*KU 49-2	
												*EL 34	

TABLE 1.1 (Cont.)

N	Z	Atom	A	I	Magnetic Moment	Q	Meth.	Std.	<u>f(x)</u>	<u>f(Std.)</u>	Tolerance	Chemical Information	Ref.	<u>f(x)</u>	
														<u>f(H)</u>	
13	11	Na	24	4	[SK 51]										
					+1.688		A	1	$\mu = 1.688$		$\pm .005$		BM 53	.07555	
					2.2							Predicted	KL 52		
13	12	Mg	25	$\frac{5}{2}$											
					- .97 (5)		S						CR 49-3		
					- .854 71 (14)		R	N^{14}	.847 14		$\pm .000 08$	4.6 m $MgCl_2$ aq. and HNO_3	AY 51-2	.061211 (11)	
13	13	Al	26	(5)											
					[+2.8 (2)]							Predicted	KL 53		
14	13	Al	27	$\frac{5}{2}$											
					+3.628 (10)		M	1	$g = 1.451$			NaCl•AlCl ₃ and KCl•AlCl ₃	ML 39-2	.2598	
					3.638 3 (4)		R	H^1	.260 56		$\pm .000 03$		BI 49	.26056 (3)	
					3.639 1 (16)		R	H^1	.260 62		$\pm .000 11$		ZI 49	.26062 (11)	
					This value in error		R	H^1	.260 568 7		$\pm .000 001 0$		LM 51		
					3.638 422 (15)		R	H^1	.260 569 4		$\pm .000 000 2$ PE $\pm .000 001 4$ XD $\pm .000 001 0$ EE	AlCl ₃ aq.	LM 51-2	.2605694 (10)	
					3.638 60 (22)		R	Sc^{45}	1.072 61		$\pm .000 05$ PE (8s)		SW 51	.260579 (16)	
					3.638 570 (11)		R	H^1	.260 579		$\pm .000 008$		KO 52	.260580 (8)	
					3.638 483 (54)		R	Na^{23}	.985 088 ⁵		$\pm .000 010$ (7m)	AlCl ₃ aq. and NaBr + .1m MnSO ₄	WL 52-5	.2605738 (39)	2

TABLE 1.1 (Cont.)

TABLE 1.1 (Cont.)

<u>N</u>	<u>Z</u>	<u>Atom</u>	<u>A</u>	<u>I</u>	<u>Magnetic Moment</u>	<u>Q</u>	<u>Meth.</u>	<u>Std.</u>	<u>$\frac{f(x)}{f(Std.)}$</u>	<u>Tolerance</u>	<u>Chemical Information</u>	<u>Ref.</u>	<u>$\frac{f(x)}{f(H)}$</u>
17	16	S	33	$\frac{3}{2}$	+ .632 (10)		S	1	g = .421		enriched S ³³	EH 50	.0754
					.633 (10)		W				OCS ³³	EH 50-2	.0755 ⁵
					.9		S				OCS ³³	JD 50	
					.642 74 (13)		R	N ¹⁴	1.061 74	$\pm .000\ 13$	CS ₂ and 3.2 N ₂ HNO ₃	DH 51-2	.076717 (15)
19	16	S	35	$\frac{3}{2}$	[CO 49]								
					[+ 1.00 (10)]						Predicted	SA 51	
					[+ 1.1]						Predicted	BB 52	
17	17	C1	34	3	+ 1.4 (1)						Predicted	KL 53	

TABLE 1.1 (Cont.)

N	Z	Atom	A	I	Magnetic Moment	Q	Meth.	Std.	f(x) f(Std.)	Tolerance	Chemical Information	Ref.	f(x) f(H)
18	17	Cl	35	$\frac{3}{2}$									
					+ .819		M	1	g = .546		LiCl	KU 39-3	.0978
					.821 10 (25)		R	Na ²³	.370 51	$\pm .000\ 11$		BI 49	.098007 (29)
					.821 0 (6)		R	H ¹	.097 99	$\pm .000\ 07$ MD (10m)	Sat. aq. LiCl	CH 49	.09799 (7)
					.821 0 (7)		R	Cl ³⁷	1.201 4	$\pm .001$	HC1	PR 50	.097985 (85)
					.820 86 (9)		R	D ²	.638 27	$\pm .000\ 06$	.6m MnSO ₄ + 85% D ₂ O and conc. HC1	PR 51	.097978 (10)
					.820 86 (71)		R	Cl ³⁷	1.201 3	$\pm .000\ 1$	aq. LiCl	WA 51	.097977 (84)
					.820 904 (43)		R	D ²	.638 301	$\pm .000\ 009$ (6m)	RbCl + D ₂ O	WL 52-2	.0979832 (16)
					.820 876 (68)		R	Rb ⁸⁵	1.014 785	$\pm .000\ 009$ (3s)(6m)	RbCl aq.	WL 52-2	.0979798 (79)
					.820 896 (68)		R	Rb ⁸⁵	1.014 81	$\pm .000\ 05$ EE ($\geq 10m$)	LiCl and RbCl	TI 52-2	.0979822 (79)
					.820 84 (74)		R	Cl ³⁷	1.201 28	$\pm .000\ 06$ EE ($\geq 10m$)	LiCl and RbCl	TI 52-2	.097975 (84)

• DI 49-3

• SC 38

19 17 Cl 36 2 [GB 52]

[+ .9]

Predicted

KL 52

TABLE 1.1 (Cont.)

N	Z	Atom	A	I	Magnetic Moment	Q	Meth.	Std.	$\frac{f(x)}{f(Std.)}$	Tolerance	Chemical Information	Ref.	$\frac{f(x)}{f(H)}$
20	17	C1	37	$\frac{3}{2}$									
					+ .681		M	1	g = .454			KU 39-3	.0813
					.683 25 (7)		R	D ²	.531 27	$\pm .000\ 05$	.6m MnSO ₄ 85% D ₂ O and conc. HCl	PR 51	.081553 (8)
					.683 34 (7)		R	Rb ⁸⁵	.844 77	$\pm .000\ 05$ EE ($\geq 10m$)	LiCl and RbCl	TI 52-2	.081564 (8)
19	19	K	38	(3)									
					[1.4 (1)]					Predicted		BB 52	
20	19	K	39	$\frac{3}{2}$	[ML 35]								
					+ .397		Z					FP 35	
					.390		M					KU 39-2	
					.391		A	1	g = .261			KU 40	.0467
					.390 94 (7)		R	N ¹⁴	.645 80	$\pm .000\ 06$	1 ml. sat. aq. KNO ₂ and HNO ₃	CL 50-2	.046663 (8)
												*TA 49	
21	19	K	40	4									
					-1.290 (5)		A	1	g = .323			ZA 42	.0578
					-1.296 4 (4)		M	1	g = -.324 10	$\pm .000\ 7$ XD (5s) .000 10 EE	metal	EI 52	.058027 (18)
					-1.296 3 (2)		M	K ³⁹	gr = -1.243 46	$\pm .000\ 24$		EI 52	.058022 (6)

TABLE 1.1 (Cont.)

<u>N</u>	<u>Z</u>	<u>Atom</u>	<u>A</u>	<u>I</u>	<u>Magnetic Moment</u>	<u>Q</u>	<u>Meth.</u>	<u>Std.</u>	<u>f(x)</u>	<u>Tolerance</u>	<u>Chemical Information</u>	<u>Ref.</u>	<u>$\frac{f(x)}{f(H)}$</u>
22	19	K	41	$\frac{3}{2}$	+ .215 06 (6)		A	K ³⁹	.550 12	$\pm .000\ 06$		KU 40 *ML 35 *KU 49-2 *TA 49 *MB 36	.025669 ⁶ (6)
23	19	K	42	2	- 1.137		A		$\mu = -1.137$	$\pm .005$		BM 53	.10179 (45)
23	20	Ca	43	$(\frac{7}{2})$	[SA 51]						Predicted	SA 51	
					[- 1.38 (10)]								
				$\frac{5}{2}$	JR 53								
					- 1.31		R				JR 53		
24	21	Sc	45	$\frac{7}{2}$	+ 4.8		S					KP 37-1	
					4.748 6 (50)	R	Na ²³	.918 3	$\pm .000\ 1$	Sc ₂ O ₃ in HNO ₃		PR 50-3	.24291 (25)
					4.748 6 (50)	R	Na ²³	.918 3	$\pm .000\ 1$	.65m Sc(NO ₃) ₂ and aq. NaCl + .5m MnSO ₄		PR 51	.24291 (25)
					4.749 14 (6)	R	H ¹	.242 939	$\pm .000\ 008\ MD$.000 003 PE	sat. .1 mol acid soln of ScCl ₃ [Sc(NO ₃) ₃]		HU 51 HU 50	.242929 (3)
					4.748 67 (74)	R	Br ⁷⁹	.969 54	$\pm .000\ 06$	NaBr and ScCl ₃		SW 50	.242915 (37)
					4.749 55 (50)	R	H ¹	.242 96	$\pm .000\ 05$ (See RN 50)	ScCl ₃		SW 50	.24296 (5)

TABLE 1.1 (Cont.)

N	Z	Atom	A	I	Magnetic Moment	Q	Meth.	Std.	$\frac{f(x)}{f(Std.)}$	Tolerance	Chemical Information	Ref.	$\frac{f(x)}{f(H)}$
25	22	Ti	47	$\frac{5}{2}$	[SA 51]								
				$\frac{5}{2}$	[JR 53]								
					[-1.79 (10)]					Predicted		SA 51	
Based on		I =	$\frac{7}{2}$		[-1.102 (2)]	R	H ¹	.056 37		$\pm .000\ 01$	TiCl ₄	JR 52-2	.05637 (1)
					-0.79	R						JR 53	
												*JR 50	
27	22	Ti	49	$\frac{7}{2}$	[SA 51, JR 52] [JR 53]								
					-1.102 2 (3)	R	H ¹	.056 38	$\pm .000\ 01$ (compd. shift observed)	TiCl ₄ liquid or H ₂ TiF ₆ aq.	JR 52	.05638 (1)	
					[- .96 (10)]					Predicted		SA 51	
					-1.102 3 (2)	R	H ¹	.056 39	$\pm .000\ 01$	TiCl ₄	JR 52-2	.05639 (1)	
												*JR 50	
27	23	V	50	6	[BC 52-2, KK 52, HI 52]								
					+3.341 19 (29)	R	Cl ³⁵	1.017 585	$\pm .000\ 015$ (3s)(6m)	VOCl ₃ and RbCl aq.	WL 52-2	.0997014 (87)	
					3.341 2 (2)	R	Rb ⁸⁵	1.032 623	$\pm .000\ 040$ (3s)(6m)	VOCl ₃ and RbCl aq.	WL 52-2	.099702 (5)	
					3.341 317 (5)	R	D ²	0.649 518	$\pm .000\ 009$ (3s)(6m)	VOCl ₃ and D ₂ O + RbCl aq.	WL 52-2	.0997050 (14)	
					3.341 4 (4)	R	1	g = .556 90	$\pm .000\ 06$		WL 52-2	.099707 (11)	
					3.34 ⁷	X	V ⁵¹	gr = .380	(g = .558)		BC 52-2	.0999	
					3.33 ⁹	X	V ⁵¹	gr = .379	(g = .556 ⁵)		KK 52	.0996 ⁴	

TABLE 1.1 (Cont.)

N	Z	Atom	A	I	Magnetic Moment	Q	Meth.	Std.	$\frac{f(x)}{f(Std.)}$	Tolerance	Chemical Information	Ref.	$\frac{f(x)}{f(H)}$
28	23	V	51	$\frac{7}{2}$									
					+5.139 6 (2)		R	Na ²³	.993 94	$\pm .000\ 03$	Pb(VO ₃) ₂ and/or V ₂ O ₅ + NaCl + HCl + H ₂ O	KG 49-2	.262915 (10)
					Sign only +		R				NaVO ₃	PR 51	
							R		agrees with KG 49-2		V ₂ O ₅ solid	SW 50-2	
					5.136 50 (24)		R	Sc ⁴⁵	1.081 56	$\pm .000\ 05$ PE (8s)	pwd. V ₂ O ₅ and aq. SeCl ₃	SW 51	.262753 (13)
					5.139 21 (59)		R	Na ²³	.993 855	$\pm .000\ 010$ (2s)(7m)	NaVO ₃	WL 52-3	.262893 (3)
					5.141 79 (4) <i>(chem. shift)</i>		R	Na ²³	.994 355	$\pm .000\ 005$ (6s)(7m)	VOCl ₃ and NaVO ₃ aq.	WL 52-3	.263025 (2)
29	24	Cr	53	$\frac{3}{2}$	[BE 51] [JR 53]								
					(\pm) .45		X					BE 51	
					.58 (1)		X					BW 52	.059
					[- .67 (10)]					Predicted		SA 51	
					-0.475		R					JR 53	

TABLE 1.1 (Cont.)

N	Z	Atom	A	I	Magnetic Moment	Q	Meth.	Std.	f(x)	Tolerance	Chemical Information	Ref.	f(x)	
									f(Std.)				f(H)	
30	25	Mn	55	$\frac{5}{2}$	+3.461 75 (37)	R	Na ²³	.937 2		$\pm .000\ 1$	2m. LiMnO ₄ (aq)	PR 51	.24791 (26)	
					3.461 75 (37)	R	Na ²³	.937 2		$\pm .000\ 1$	2m. LiMnO ₄ (aq) and .25m NaCl + 1m MnSO ₄	PR 50	.24791 (26)	
					3.461 0 (17)	R	H ¹	.247 86		$\pm .000\ 12$	Ca(MnO ₄) ₂ aq.	SW 50-2	.24786 (12)	
					3.461 05 (35)	R	Sc ⁴⁵	1.020 28		$\pm .000\ 05$ PE(8s)	Ca(MnO ₄) ₂ and ScCl ₃	SW 51	.247867 (18)	
											*FI 39			
											*WH 30			
31	26	Fe	57	$\left(\frac{3}{2}\right)$	[SA 51]									
					0.0		S				GV 49-2			
											BS 49			
					[- .66 (10)]					Predicted	SA 51			
											*RW 50			
30	27	Co	57	$\frac{7}{2}$	[BC 53]									
					4.6 (2)	X		$\mu = 4.6$		$\pm .2$		BC 53		
31	27	Co	58	2										
					+3.5 (3)	NL	I	$\mu = 3.5$		$\pm .3$		DS 52		
											GA 52			
32	27	Co	59	$\frac{7}{2}$	+4.638 85 (47)	R	Na ²³	.897 09		$\pm .000\ 09$	1 mol. aq. K ₃ Co(CN) ₆	PR 50 PR 51	.237297 (24)	
33	27	Co	60	5	[DS 52]									
					+3.5 (5)	NL		3.5		$\pm .5$		DS 52		
					3.2	NL		3.2				GR 52 GA 52		
					3.0	NL		$\mu = 3.0$				RE 52		
											*MO 34			

TABLE 1.1 (Cont.)

<u>N</u>	<u>Z</u>	<u>Atom</u>	<u>A</u>	<u>I</u>	<u>Magnetic Moment</u>	<u>Q</u>	<u>Meth.</u>	<u>Std.</u>	<u>$f(x)$</u> <u>$f(Std.)$</u>	<u>Tolerance</u>	<u>Chemical Information</u>	<u>Ref.</u>	<u>$f(x)$</u> <u>$f(H)$</u>
33	28	Ni	61	($\frac{3}{2}$)	[SA 51]				unpublished - See JE 32				
							S					AR 50	
					<.25		S			80% Ni ⁶¹		KM 50	
					[+ .10 (10)]					Predicted		SA 51	
34	29	Cu	63	($\frac{3}{2}$)									
					+2.221 0 (5)	R	Na ²³	1.002 2		$\pm .000\ 2$	NaBr aq. + CuCl ₂	PO 48	.26510 (6)
					2.220 64 (45)	R	H ¹	.265 056		$\pm .000\ 053$		BI 49	.265056 (53)
					2.221 4 (5)	R	H ¹	.265 15		$\pm .000\ 05$	Cu ₂ Cl ₂ + CuCl ₂ aq.	ZI 49	.26515 (5)
					2.221 08 (16)	R	Sc ⁴⁵	1.091 25		$\pm .000\ 06$ PE (8s)	pwd. Cu ₂ Cl ₂ , ScCl ₃ aq.	SW 51	.265108 (19)
					2.225 825 (27)	R	Na ²³	1.004 372		$\pm .000\ 012$ (7m)	metal powder	WL 52-5	.2656747 (32)
					2.220 59 (4)	R	Na ²³	1.002 009		$\pm .000\ 012$ (7m)	CuCl ₂ + Cu ₂ Cl ₂ (aq. soln)	WL 52-5	.265050 (4)
											*GQ 33		
											*SH 36-2		
											*SH 37-2		

TABLE 1.1 (Cont.)

<u>N</u>	<u>Z</u>	<u>Atom</u>	<u>A</u>	<u>I</u>	<u>Magnetic Moment</u>	<u>Q</u>	<u>Meth.</u>	<u>Std.</u>	<u>f(x)</u>	<u>Tolerance</u>	<u>Chemical Information</u>	<u>Ref.</u>	<u>f(x)</u>
								<u>f(Std.)</u>					<u>f(H)</u>
36	29	Cu	65	$\frac{3}{2}$									
					+2.378 5 (5)		R	Cu ⁶³	1.071 1	$\pm .000\ 2$	Cu ₂ Cl ₂	PO 48	.28390 (6)
					2.378 6 (5)		R	H ¹	.283 91	$\pm .000\ 057$		BI 49	.28391 (6)
					2.379 69 (76)		R	H ¹	.284 04	$\pm .000\ 09$	Cu ₂ Cl ₂ , CuCl ₂ aq.soln.	ZI 49	.28404 (9)
					2.380 39 (18)		R	Sc ⁴⁵	1.169 51	$\pm .000\ 06\ (8s)$	pwd. Cu ₂ Cl ₂ and ScCl ₃ aq.	SW 51	.284120 (21)
					2.380 02 (22)		R	Cu ⁶³	1.071 78	$\pm .000\ 05\ (8s)$	pwd. Cu ₂ Cl ₂	SW 51	.284079 (26)
					2.384 47 (5)		R	Na ²³	1.075 958	$\pm .000\ 020$	Metal	WL 52-5	.2846105 (53)
					2.378 96 (3)		R	Na ²³	1.073 470	$\pm .000\ 012$	CuCl ₂ + Cu ₂ Cl ₂ aq. sol.	WL 52-5	.2839524 (35)
											*GQ 33		
											* SH 36-2		
											* SH 37-2		
37	30	Zn	67	$\frac{5}{2}$									
					+ .9		S					LY 37	
					+ .873 53 (10)		R	N ¹⁴	.865 80	$\pm .000\ 01$	2m. Zn(NH ₃) ₄ ⁺⁺	DH 52	.062559 (7)

TABLE 1.1 (Cont.)

<u>N</u>	<u>Z</u>	<u>Atom</u>	<u>A</u>	<u>I</u>	<u>Magnetic Moment</u>	<u>Q</u>	<u>Meth.</u>	<u>Std.</u>	<u>$\frac{f(x)}{f(Std.)}$</u>	<u>Tolerance</u>	<u>Chemical Information</u>	<u>Ref.</u>	<u>$\frac{f(x)}{f(H)}$</u>
37	31	Ga	68	1	[MK 50]								
38	31	Ga	69	$\frac{3}{2}$									
			+2.010	75 (20)		R	Na ²³	.907 320		$\pm .000\ 010$	GaCl ₃ + NaCl + HCl	WL 52-5	.240003 (24)
			1.995	7 (42)		S	H ¹	$\mu r = .714\ 6$		$\pm .001\ 5$		KU 50	.23821 (50)
											*SH 36-4		
											*RZ 40		
											*PO 48-2		
											*BE 50		
40	31	Ga	71	$\frac{3}{2}$									
			+2.554	82		A	Ga ⁶⁹	1.270 59				BG 48	.304945
			2.554	9 (10)		R	Na ²³	1.152 9	$\pm .000\ 4$	GaCl ₃ aq.	PO 48-2	.30496 (11)	
			2.553	8 (9)		R	Ga ⁶⁹	1.270 1	$\pm .000\ 4$	GaCl ₃ aq.	PO 48-2	.30483 (11)	
			2.554	932 (34)		R	Na ²³	1.152 877	$\pm .000\ 015\ (7m)$	GaCl ₃ + NaCl	WL 52-5	.3049569 (40)	
			2.535	(5)		S	H ¹	$\mu r = .907\ 8$	$\pm .001\ 5$ (shows 0.7% difference in h.f.s. and nuc. res. methods)		KU 50		
											*SH 36-4		
											*RZ 40		

TABLE 1.1 (Cont.)

N	Z	Atom	A	I	Magnetic Moment	Q	Meth.	Std.	$\frac{f(x)}{f(Std.)}$	Tolerance	Chemical Information	Ref.	$\frac{f(x)}{f(H)}$
41	32	Ge	73	$\frac{9}{2}$									
					[-1.39]						Predicted	SA 51	
					[-1.0]						Predicted	BB 52	
42	33	As	75	$\frac{3}{2}$									
					S							MW 50	
					+1.434 83 (33)	R	Na ²³	.647 45		$\pm .000\ 15$	2m. Na ₂ HAsO ₄ in 3m. NaOH	DH 51	.171262 (39)
					1.435 07 (25)	R	H ¹	.171 29		$\pm .000\ 03$	1.2m. aq. Na ₃ AsS ₄	JR 52	.17129 (3)
					1.434 86 (7)	R	D ²	1.115 69		$\pm .000\ 05\ EE\ (\geq 10m)$	Na ₂ HAsO ₄ + NaOH and D ₂ O + NiCl ₂	TI 52-2	.171265 (8)
					1.44	S					*GQ 33		
											*SH 35-2		
											*SH 36-2		
											*JR 50		
											KQ 52		
43	34	Se	77	$\frac{1}{2}$	[(DA 51)]								
					+ .533 29 (15)	R	Na ²³	.721 93		$\pm .000\ 02$	12m. H ₂ SeO ₃	DH 52-2	.190964 (5)
					.532 48 (4) (chem. shift)	R	D ²	1.242 109		$\pm .000\ 026\ PE\ (7m)$.000 1 EE	H ₂ Se + D ₂ O	WL 52-4	.190671 (15)

TABLE 1.1 (Cont.)

<u>N</u>	<u>Z</u>	<u>Atom</u>	<u>A</u>	<u>I</u>	<u>Magnetic Moment</u>	<u>Q</u>	<u>Meth.</u>	<u>Std.</u>	<u>$\frac{f(x)}{f(Std.)}$</u>	<u>Tolerance</u>	<u>Chemical Information</u>	<u>Ref.</u>	<u>$\frac{f(x)}{f(H)}$</u>
45	34	Se	79	$\frac{7}{2}$	[HR 52]								
44	35	Br	79	$\frac{3}{2}$									
					+2.110 (21)		M					BR 47	
					2.099 3 (1)	R	Br ⁸¹	.927 81 ⁵		$\pm .000\ 3$	LiBr, NaBr aq.	PO 47	.25057 (1)
					2.099 4 (4)	R	H ¹	.250 59		$\pm .000\ 05$	NaBr aq.	ZI 49	.25059 (5)
					2.099 38 (14)	R	Sc ⁴⁵	1.031 45		$\pm .000\ 05$	NaBr aq. and ScCl ₃ aq.	SW 51	.250583 (16)
					2.098 99 (8)	R	Na ²³	.947 140		$\pm .000\ 008\ (7m)$	NaBr aq.	WL 52-5	.250536 (3)
												*CA 38	
												*SC 38	

TABLE 1.1 (Cont.)

N	Z	Atom	A	I	Magnetic Moment	Q	Meth.	Std.	f (x)	Tolerance	Chemical Information	Ref.	f (x)
									f (Std.)				f (H)
46	35	Br	81	$\frac{3}{2}$	+2.271 (23)		M					BR 47	
					2.262 5 (7)	R	Na ²³	1.020 9		$\pm .000\ 3$	LiBr or NaBr aq.	PO 47	.27005 (8)
					2.262 4 (7)	R	Br ⁷⁹	1.077 8		$\pm .000\ 3$	LiBr aq. or NaBr aq.	PO 47	.27004 (8)
					2.263 2 (5)	R	H ¹	.270 14		$\pm .000\ 05$	NaBr aq.	ZI 49	.27014 (5)
					2.263 1 (7)	R	H ¹	.270 03		$\pm .000\ 08$		BI 49	.27003 (8)
					2.262 62 (13)	R	Sc ⁴⁵	1.111 65		$\pm .000\ 06\ (8s)$	NaBr aq. and ScCl ₃ aq.	SW 51	.270066 (15)
					2.262 28 (17)	R	Br ⁷⁹	1.077 75		$\pm .000\ 05\ (8s)$	NaBr aq.	SW 51	.270026 (20)
					2.262 62 (4)	R	Na ²³	1.020 97 ⁵		$\pm .000\ 013\ (7m)$	NaBr aq.	WL 52-5	.270066 (4)
					2.262 61 (13)	R	Br ⁷⁹	1.077 90 ⁶		$\pm .000\ 018\ (7m)$	NaBr aq.	WL 52-5	.270065 (15)
											*SC 38		
											*CA 33		
47	36	Kr	83	$\frac{9}{2}$	- .967	1	g = .214 8				KE 46	.03846	

TABLE 1.1 (Cont.)

<u>N</u>	<u>Z</u>	<u>Atom</u>	<u>A</u>	<u>I</u>	<u>Magnetic Moment</u>	<u>Q</u>	<u>Meth.</u>	<u>Std.</u>	<u>f(x)</u>	<u>Tolerance</u>	<u>Chemical Information</u>	<u>Ref.</u>	<u>f(x)</u>
								<u>f(Std.)</u>					<u>f(H)</u>
48	37	Rb	85	$\frac{5}{2}$									
					+1.340 (5)		M				Rb ₂	KU 39-3	
					1.348 6 (4)	R	Na ²³	.365 12	$\pm .000\ 11$			BI 49	.096581 (29)
					1.349 (1)	R	H ¹	.096 61	$\pm .000\ 04$ AD	Rb ₂ CO ₃	CH 49	.09661 (4)	
					1.348 190 (5)	R	H ¹	.096 552 08	$\pm .000\ 000\ 1$ PE .000 000 3	RbCl sat. aq.	YA 51	.09655208 (30)	
					1.348 22 (14)	R	D ²	.628 994	$\pm .000\ 06$	RbCl + D ₂ O + H ₂ O	WL 52-2	.0965545 (99)	
					1.348 2 (2 ²)	R	Cl ³⁵	.985 41	$\pm .000\ 15$	RbCl + D ₂ O + H ₂ O	WL 52-2	.096553 (16)	
					1.348 228 (13)	R	D ²	.628 996	$\pm .000\ 008$	RbCl + D ₂ O + H ₂ O	WL 52-2	.09655479 (126)	
					1.348 23 (3)	R	Cl ³⁵	.985 430	$\pm .000\ 008$	RbCl + D ₂ O + H ₂ O	WL 52-2	.096555 (2)	
											*KU 49-2		
											*KP 33		
49	37	Rb	86	2									
					-1.66 (40)		A					BM 51	
					-1.69 (01)	A	1	$\mu = -1.69$	$\pm .01$			BM 53	

TABLE 1.1 (Cont.)

N	Z	Atom	A	I	Magnetic Moment	Q	Meth.	Std.	f(x) f(Std.)	Tolerance	Chemical Information	Ref.	f(x) f(H)
50	37	Rb	87	$\frac{3}{2}$									
					+2.741 (9)		M	Rb ⁸⁵	$\mu r = 2.038$	$\pm .010$	Rb ₂	KU 39-3	
					2.741 52 (12)		R	H ¹	.327 228	$\pm .000\ 014$ (21m)	RbCl aq.	AD 49	.327228 (14)
					2.741 1 (6)		R	H ¹	.327 18	$\pm .000\ 07$		BI 49	.32718 (7)
					2.741 1 (14)		R	H ¹	.327 18	$\pm .000\ 16$	Rb ₂ CO ₃ aq.	ZI 49	.32718 (16)
					2.741 397 0 (47)		R	H ¹	.327 213 38	$\pm .000\ 000\ 55$	RbCl sat. aq.	YA 51	.32721338 (55)
					2.740 37 (14)		R	Al ²⁷	1.255 29	$\pm .000\ 06$	AlCl ₃ aq. and Rb ₂ CO ₃ + CuCl ₂ aq.	SW 51	.327091 (16)
					2.741 464 (61)		R	Rb ⁸⁵	$\mu r = 2.033\ 380$	$\pm .000\ 028$ XD (37m)	RbCl aq.	AD 51 BI 51	.3272217 (45)
					2.741 458 (24)		R	Na ²³	1.237 044	$\pm .000\ 007$ PE	RbCl aq.	WL 52-2 WL 52-5	.3272207 (28)
					2.731 7 (4)		M	Rb ⁸⁵	$\mu r = 2.026\ 1$	$\pm .000\ 3$	calculated from h.f.s.	ML 40	
											*KP 33		
49	38	Sr	87	$\frac{9}{2}$									
					-1.1		S					HN 38	.044

TABLE 1.1 (Cont.)

N	Z	Atom	A	I	Magnetic Moment	Q	Meth.	Std.	$\frac{f(x)}{f(Std.)}$	Tolerance	Chemical Information	Ref.	$\frac{f(x)}{f(H)}$
50	39	Y	89	$\frac{1}{2}$	- ≤ .1		S					WK 40	
					- .14		S			YCl ₃		CR 49-4	.050
						S			Confirms CR 49-4			KN 50	
51	40	Zr	91	$\frac{5}{2}$	[- .99 (10)]		T			Predicted		SA 51	
					-1.1 (3)		S			ZrI		SU 52	.079 (2)
					-1.0		T			Predicted		BB 52	
52	41	Nb	93	$\frac{9}{2}$	+5.3		S	1	g = 1.18			MF 47	
					+6.143 8 (33)		R	B ¹¹	.761 87	± .000 40	Nb ₂ O ₅ in HF	SW 50-3	.24444 (13)
					6.143 54 (40)		R	Sc ⁴⁵	1.006 13	± .000 05 PE (8s)	Nb ₂ O ₅ + HF and SbCl ₃	SW 51	.244431 (16)
											*CH 50		

TABLE 1.1 (Cont.)

N	Z	Atom	A	I	Magnetic Moment	Q	Meth.	Std.	<u>f(x)</u>	<u>f(Std.)</u>	Tolerance	Chemical Information	Ref.	<u>f(x)</u>
														<u>f(H)</u>
53	42	Mo	95	$\frac{5}{2}$	[AR 50]									
					- .929 0 (1)		R	N ¹⁴	.920 8		$\pm .000\ 1$	HNO ₃ and K ₂ MoO ₄ sat. aq.	PR 51	.066533 (13)
55	42	Mo	97	$\frac{5}{2}$	[AR 50]									
					- .948 5 (1)		R	Mo ⁹⁵	1.021 0		$\pm .000\ 1$	K ₂ MoO ₄ sat. aq.	PR 51	.067930 (7)
56	43	Tc	99	$\frac{9}{2}$	[KM 51]									
					+5.657 24 (40)		R	D ²	1.466 28		$\pm .000\ 1$	NH ₄ TcO ₄ aq. + D ₂ O	WL 52	.225083 (16)
					+5.3 (5)		S				(corrected for finite nuclear size)		KM 51-2	
55	44	Ru	99	$\frac{5}{2}$	[GF 52]									
57	44	Ru	101	$\frac{5}{2}$	[GF 52]									
							S	Ru ⁹⁹	$\mu r = 1.09$		$\pm .03$	Ru(NH ₃) ₆ Cl ₃ + Co(NH ₃) ₆ Cl ₃	GF 52	

TABLE 1.1 (Cont.)

N	Z	Atom	A	I	Magnetic Moment	Q	Meth.	Std.	$\frac{f(x)}{f(Std.)}$	Tolerance	Chemical Information	Ref.	$\frac{f(x)}{f(H)}$
58	45	Rh	103	$\frac{1}{2}$	[SM 37]								
			(-)	.11			S					KN 50-2	
				+ .1			T			Predicted		BB 52	
59	46	Pd	105	$\frac{5}{2}$	[BX 51]								
				[-.6]			S					BX 51	.043
				-.57 (5)			S					ST 52	
				$\frac{5}{2}$	-.57		S					BA 53	
60	47	Ag	107	$\frac{1}{2}$									
				-.086			S					CR 49	.031
				-.087			S					CR 50	
				-.10			S	Calc. by Goudsmit formula.				JA 37	.036
				-.111 (8)			S					BX 51-2	
62	47	Ag	109	$\frac{1}{2}$									
				-.159			S					CR 49	.057
				-.160			S					CR 50	
				-.19			S					JA 37	.068
				-.129 (8)			S					BX 51-2	

TABLE 1.1 (Cont.)

N	Z	Atom	A	I	Magnetic Moment	Q	Meth.	Std.	<u>f(x)</u>	<u>Tolerance</u>	<u>Chemical Information</u>	<u>Ref.</u>	<u>f(x)</u>	
									<u>f(Std.)</u>				<u>f(H)</u>	
63	48	Cd	111	$\frac{1}{2}$										
					$[-1.25]$		S					JO 33		
					- .592 16 (8)		R	Na ²³	.801 6	$\pm .000\ 1\ (4s)$.1m NaCl + .2m MnSO ₄ and CdCl ₂ in .3m MnSO ₄ (80% Cd ¹¹¹)	PR 49-3	.21204 (2 ⁷)	
					-0.85		γ		$\mu(d\frac{5}{2}) = -.85$	$\pm .22$		PR 50-2		
					-0.70		γ				*GQ 33	AL 51		
											AL 52			
65	48	Cd	113	$\frac{1}{2}$										
					$[-1.25]$		S				Cd ¹¹³	JO 33		
					- .619 47 (8)		R	Na ²³	.838 6	$\pm .000\ 1$	sat.CdCl ₂ (80% Cd ¹¹³) in .1m MnSO ₄	PR 49-3	.22182 (2 ⁷)	
					- .619 47 (11)		R	Cd ¹¹¹	1.046 1	$\pm .000\ 1$	"	PR 50-2	.22182 (4)	
											*GQ 33			
64	49	In	113	$\frac{9}{2}$										
					+5.496 0 (5)		R	Na ²³	.826 67	$\pm .000\ 08$.38m In(NO ₃) ₂ and .25 m NaCl + .5m MnSO ₄	PR 51	.218669 (21)	
											*HD 42			
											*TA 49			

TABLE 1.I (Cont.)

<u>N</u>	<u>Z</u>	<u>Atom</u>	<u>A</u>	<u>I</u>	<u>Magnetic Moment</u>	<u>Q</u>	<u>Meth.</u>	<u>Std.</u>	<u>f(x)</u> <u>f(Std.)</u>	<u>Tolerance</u>	<u>Chemical Information</u>	<u>Ref.</u>	<u>f(x)</u> <u>f(H)</u>
66	49	In	115	$\frac{9}{2}$									
					+5.49 (4)		S					HD 42	
					5.508 4 (8)		S	In ¹¹³	1.002 24	$\pm .000\ 10$		MD 50	.21916 (3)
					5.507 6 (8)		R	In ¹¹³	1.002 1	$\pm .000\ 1$		PR 51	.21913 (3)
					+5.507 59 (53)		R	Na ²³	.828 41	$\pm .000\ 08$	.38m aq. In(NO ₃) ₂ and .25m NaCl + .5m MnSO ₄	PR 51	.219129 (21)
					5.509 51 (30)		R	Sc ⁴⁵	.902 292	$\pm .000\ 010\ PE$ $\pm .000\ 050\ EE$	InNO ₃ in 30% HNO ₃ and SeCl ₃ aq. + MnSO ₄	TI 52	.219205 (12)
					5.507 75 (70)		R	In ¹¹³	1.002 13	$\pm .000\ 04\ EE\ (\geq 10m)$	In(NO ₃) ₃	TI 52-2	.219135 (28)
					5.506 94 (30)		R	Sc ⁴⁵	.901 877	$\pm .000\ 05\ EE\ (\geq 10m)$	SeCl ₃ and In(NO ₃) ₃ + Mn(NO ₃) ₂	TI 52-2	.219103 (12)
											*SH 37		
											*ML 38		
											*KU 48		
											*TA 49		
65	50	Sn	115	$\frac{1}{2}$									
					- .913 195 (76)		R	Na ²³	1.236 2	$\pm .000\ 1\ (5s)$	at ~100°C. SnCl ₂ ·2H ₂ O + .2m MnSO ₄	PR 49-3	.326997 (27)
					.913 195 (76)		R	Na ²³	1.236 2	$\pm .000\ 1$	~12m. SnCl ₂ + .7m MnSO ₄ and .2m NaCl + .2m MnSO ₄	PR 50-2	.326997 (27)
											*GV 49	4	

TABLE 1.1 (Cont.)

<u>N</u>	<u>Z</u>	<u>Atom</u>	<u>A</u>	<u>I</u>	<u>Magnetic Moment</u>	<u>Q</u>	<u>Meth.</u>	<u>Std.</u>	<u>f(x)</u> <u>f(Std.)</u>	<u>Tolerance</u>	<u>Chemical Information</u>	<u>Ref.</u>	<u>f(x)</u> <u>f(H)</u>
67	50	Sn	117	$\frac{1}{2}$									
					- .994 601 (98)		R	Na ²³	1.346 4	$\pm .000\ 4$	5.3m SnCl ₂ + 1m MnCl ₂ and .69m NaCl + 1m MnCl ₂	PR 49-2	.356147 (35)
					- .994 897 (25)		R	Na ²³	1.346 8	$\pm .000\ 1$	See PR 49-2	PR 50-2	.356253 (9)
					- .994 89 (13)		R	Sn ¹¹⁵	1.089 4 ⁷	$\pm .000\ 1$	See PR 49-2	PR 50-2	.356253 (45)
											*TL 33		
											*TL 41		
69	50	Sn	119	$\frac{1}{2}$									
					-1.040 86 (36)		R	Na ²³	1.409 0	$\pm .000\ 5$	See Sn ¹¹⁷ PR 49-2	PR 49-2	.37271 (13)
					-1.040 86 (36)		R	Na ²³	1.409 0	$\pm .000\ 1$	See Sn ¹¹⁷ PR 49-2	PR 50-2	.37271 (3)
							R	Sn ¹¹⁷	1.046 5	$\pm .000\ 3$	See Sn ¹¹⁷ PR 49-2	PR 50-2	.37281 (33)
											*TL 33		
											*TL 41		

TABLE 1-1 (Cont.)

TABLE 1.1 (Cont.)

N	Z	Atom	A	I	Magnetic Moment	Q	Meth.	Std.	$\frac{f(x)}{f(Std.)}$	Tolerance	Chemical Information	Ref.	$\frac{f(x)}{f(H)}$
71	52	Te	123	$\frac{1}{2}$									
					- .62 (20)		S					RM 51	.222
					- .731 95 (23)		R	Na ²³	.990 85	$\pm .000\ 03$	TeO ₂ in HCl (3.1m) or Te in aqua regia	DH 51-3	.262097 (80)
					- .77		S	Te ¹²⁵	$\mu r = .88$		Te ¹²³ 45% enriched	FO 50	.276
					- .5		S		- .5	$\pm .2$		RM 52	
73	52	Te	125	$\frac{1}{2}$									
					- .884 (4)		S	Te ¹²³	$\mu r = 1.208$	$\pm .06$		MA 49-2	.318
					- .74 (20)		S					RM 51	.266
					- .882 44 (26)		R	Na ²³	1.194 57	$\pm .000\ 04$	TeO ₂ in HCl (3.1m)	DH 51-3	.315985 (94)
					- .83		S	Te ¹²³	$\mu r = 1.136$		Te ¹²⁵ 80% enriched	FO 50	.298
					- .6		S		- .6	$\pm .2$		RM 52	
73	53	I	126	2	[SE 51]								

TABLE 1.1 (Cont.)

N	Z	Atom	A	I	Magnetic Moment	Q	Meth.	Std.	f(x)	f(Std.)	Tolerance	Chemical Information	Ref.	f(x) f(H)
74	53	I	127	$\frac{5}{2}$										
					+2.794 69 (74)		R	Na ²³	.756 64		$\pm .000\ 2$	NaI solid or NaI aq.	PO 48-2	.200145 (53)
					2.793 1 (98)		R	H ¹	.200 03		$\pm .000\ 07$	KI aq.	ZI 49	.20003 (7)
					2.793 72 (44)		R	D ²	1.303 37		$\pm .000\ 2\ EE$	Iodine in Hydrazine + D ₂ O	WL 51	.200075 (31)
					2.793 994 (98)		R	H ¹	.200 094 8		$\pm .000\ 007\ 0$	KI aq.	YA 51	.2000948 (70)
					2.793 29 (13)		R	D ²	1.303 17		$\pm .000\ 06\ PE\ (8s)$	KI + D ₂ O + NiCl ₂ aq.	SW 51	.2000447 (92)
												*GO 48		
76	53	I	129	$\frac{7}{2}$										
					+2.603 04 (32)		R	D ²	.867 44		$\pm .000\ 1\ EE$	27 mg I in Hydrazine + D ₂ O	WL 51	.133157 (16)
					2.72			W					GO 48	
78	53	I	131	$\frac{9}{2}$	[DO 42]									

TABLE 1.1 (Cont.)

<u>N</u>	<u>Z</u>	<u>Atom</u>	<u>A</u>	<u>I</u>	<u>Magnetic Moment</u>	<u>Q</u>	<u>Meth.</u>	<u>Std.</u>	<u>$\frac{f(x)}{f(Std.)}$</u>	<u>Tolerance</u>	<u>Chemical Information</u>	<u>Ref.</u>	<u>$\frac{f(x)}{f(H)}$</u>
75	54	Xe	129	$\frac{1}{2}$									
					- .7		S	Xe ¹³¹	$\mu r = -1.11$			KP 34	.250
					- .772 40 (76)		R	Na ²³	1.045 6	$\pm .000\ 1$	Xe + Fe ₂ O ₃ at 12 atm. and .25m NaCl + .5m MnSO ₄	PR 50-3	.27658 (2 ⁷)
					- .772 48 (76)		R	Na ²³	1.045 7	$\pm .000\ 1$	"	PR 51	.27661 (2 ⁷)
								Xe ¹³¹	$\mu r = -1.31$	$\pm .005$	XeI	BH 52	
												BT 36	
77	54	Xe	131	$\frac{3}{2}$									
					+ .696		S	Xe ¹²⁹	$\mu r = .901$			KP 34	.821
					.8		T,S					BT 36	.957
					- .683 (3)				$\mu = -.683$	$\pm .003$	XeI	BH 52	
76	55	Cs	131	$\frac{5}{2}$	[BM 53]								
					+3.48		A	1	$\mu = 3.48$	$\pm .04$		BM 53	

TABLE 1.1 (Cont.)

<u>N</u>	<u>Z</u>	<u>Atom</u>	<u>A</u>	<u>I</u>	<u>Magnetic Moment</u>	<u>Q</u>	<u>Meth.</u>	<u>Std.</u>	<u>$f(x)$</u>	<u>$f(Std.)$</u>	<u>Tolerance</u>	<u>Chemical Information</u>	<u>Ref.</u>	<u>$\frac{f(x)}{f(H)}$</u>
78	55	Cs	133	$\frac{7}{2}$	+2.555		Z					CS ₂	KU 39-2	.13070
					2.572		A						NA 49	.13157
					2.563 56 (77)	R	Li ⁷	.337 43		$\pm .000\ 10$			BI 49	.131137 (39)
					2.549 5 (26)	R	H ¹	.130 93		$\pm .000\ 14$ AD (10m)	CsCl + H ₂ O	CH 49	.13093 (14)	
						M		$\frac{gH^a}{gj} = 15.1911 \times 10^{-4}$				TA 49		
					2.569 (8)	R	1	g = .734		$\pm .002^2$			ZI 49-2	.13142 (41)
					2.564 20 (12)	R	D ²	.854 49		$\pm .000\ 04$			SW 51	.131170 (6)
					2.564 221 (28)	R	D ²	.854 499 ⁷		$\pm .000\ 009$ PE (12m) .000 088 XD	CsNO ₃ + H ₂ O + .3m D ₂ O	WL 52-5	.1311710 (14)	
79	55	Cs	134 (4)		[JC 52] [BM 53]									
					+2.96 (1)		A				200 millicuries Cs (Cs ¹³⁴) ₂ CO ₃	JC 52	.1325 (5)	
					2.95 (1)	A	1	$\mu = 2.95$		$\pm .01$			BM 53	
80	55	Cs	135	$\frac{7}{2}$	+2.721 (10)		A						NA 49	.13919 (5)
					2.724 (10)		A				CsCl aq. 50% enriched	DI 49-2	.13934 (5)	

a. See original reference for meaning.

TABLE 1.1 (Cont.)

N	Z	Atom	A	I	Magnetic Moment	Q	Meth.	Std.	$\frac{f(x)}{f(Std.)}$	Tolerance	Chemical Information	Ref.	$\frac{f(x)}{f(H)}$
82	55	Cs	137	$\frac{7}{2}$									
			+2.833				A					NA 49	.14492
			2.833 (10)				A				CsCl	DI 49-2	.14492 (5)
			2.837 (10)				A					DI 49	.14512 (5)
79	56	Ba	135	$\frac{3}{2}$									
			+ .830 6 (24)				M	1	g = .553 7	$\pm .001 6$ uncorr.	99% Ba Metal	HH 41	
81	56	Ba	137	$\frac{3}{2}$									
			+ .929 0 (27)				M		g = .619 3	$\pm .001 8$ uncorr.	99% Ba Metal	HH 41	
							M		Ba ¹³⁵ gr = 1.118 4			HH 41	
81	57	La	138										

TABLE 1.1 (Cont.)

N	Z	Atom	A	I	Magnetic Moment	Q	Meth.	Std.	$\frac{f(x)}{f(Std.)}$	Tolerance	Chemical Information	Ref.	$\frac{f(x)}{f(H)}$
82	57	La	139	$\frac{7}{2}$									
					+2.52		S	1	g = .719			AO 34-2	
					+2.761 27 (28)		R	H ¹	.141 251	$\pm .000\ 014$ MD (6m)	LaCl ₃ aq.	DN 49-2	.141251 (14)
					2.759 5 (28)		R	H ¹	.141 16	$\pm .000\ 14$ AD (10m)	aq. LaCl ₃	CH 49	.14116 (14)
					2.761 53 (18)		R	D ²	.920 25	$\pm .000\ 06$ PE (8s)	LaCl ₃ aq. + CuCl ₂ and D ₂ O + NiCl ₂	SW 51	.141264 (9)
												*WK 40	
82	59	Pr	141	$\frac{5}{2}$									
					+3.8		S			Calculated by P. Brix., and reported in		ST 52-2	
					3.8 (4)		A					LW 53	
					3.9 (3)		S		3.9	$\pm .3$		BX 53	
83	60	Nd	143	$\frac{7}{2}$	[BE 51-2]								
					-1.0 (2)		S	Nd ¹⁴⁵	$\mu r = 1.60$	$\pm .06$	enriched Nd	MW 51	
							S	Nd ¹⁴⁵	$\mu r = 1.61$	$\pm .01$	Nd ethyl sulphate	BE 51-2 BE 50	

TABLE 1.1 (Cont.)

<u>N</u>	<u>Z</u>	<u>Atom</u>	<u>A</u>	<u>I</u>	<u>Magnetic Moment</u>	<u>Q</u>	<u>Meth.</u>	<u>Std.</u>	<u>f(x)</u>	<u>f(Std.)</u>	<u>Tolerance</u>	<u>Chemical Information</u>	<u>Ref.</u>	<u>f(x)</u>
														<u>f(H)</u>
85	60	Nd	145	$\frac{7}{2}$	[BE 51-2]				-0.62 (9)	S Nd ¹⁴³ $\mu r = .625$	$\pm .023$		MW 51	
							S			Nd ¹⁴³ $\mu r = .621$	$\pm .004$		BE 50	
									- .65 (4)			corrected for finite nuclear size	MW 51	
86	61	Pm	147	$\frac{7}{2}$										
85	62	Sm	147	$\frac{7}{2}$	[BO 52]				- .67 (10)	X Sm ¹⁴⁹ $\mu r = 1.222$	$\pm .008$	Sm ethyl Sulphate	BO 52	
							X		.68 (10)				EO 52	
							S		- (sign only)	Sm ¹⁴⁹ $\mu r = 1.177$	$\pm .015$	enriched Sm	MW 51	
87	62	Sm	149	$\frac{7}{2}$	[BO 52]				- .55 (10)	S			EO 52	

TABLE 1.1 (Cont.)

N	Z	Atom	A	I	Magnetic Moment	Q	Meth.	Std.	f(x) f(Std.)	Tolerance	Chemical Information	Ref.	f(x) f(H)
88	63	Eu	151	$\frac{5}{2}$	+3.6		S	1	$\mu = 3.4$	corrected for finite nuclear size	SC 38		
							S		Eu^{153}	$\mu_r = 2.2$	SH 35-2		
90	63	Eu	153	$\frac{5}{2}$	+1.6		S	1	$\mu = 1.5$	corrected for finite nuclear size	SC 38		
							S		Eu^{151}	$\mu_r = .45$	SH 35-2		
91	64	Gd	155	$(\frac{7}{2}, \frac{9}{2})$	[EO 52]								
				$\geq \frac{3}{2}$	[SU 52]								
					+ .3 (2)		S			GdI	SU 52-		
93	64	Gd	157	$(\frac{7}{2}, \frac{9}{2})$	[EO 52]								
				$\geq \frac{3}{2}$	[SU 52]								
					+ .3 (2)		S			GdI	SU 52-		

TABLE 1.1 (Cont.)

<u>N</u>	<u>Z</u>	<u>Atom</u>	<u>A</u>	<u>I</u>	<u>Magnetic Moment</u>	<u>Q</u>	<u>Meth.</u>	<u>Std.</u>	<u>$\frac{f(x)}{f(Std.)}$</u>	<u>Tolerance</u>	<u>Chemical Information</u>	<u>Ref.</u>	<u>$\frac{f(x)}{f(H)}$</u>
94	65	Tb	159	$\frac{3}{2}$									
					$[+ .45]$		T				Predicted	BB 52	
					$[+1.]$		T				Predicted	RI 50	
95	66	Dy	161	$(\frac{7}{2}, \frac{9}{2})$	$[\text{EO } 52]$								
97	66	Dy	163	$(\frac{7}{2}, \frac{9}{2})$	$[\text{EO } 52]$								
98	67	Ho	165	$\frac{7}{2}$									
					$[+2.4]$		T				Predicted	RI 50	
					$[+3.3]$		T				Predicted	BB 52	
99	68	Er	167	$\frac{7}{2}$	$[\text{BE } 51-3]$								
100	69	Tm	169	$\frac{1}{2}$									
					$[+ .8]$		T				Predicted	RI 50	55
					$[- .15]$		T				Predicted	BB 52	

TABLE 1.1 (Cont.)

<u>N</u>	<u>Z</u>	<u>Atom</u>	<u>A</u>	<u>I</u>	<u>Magnetic Moment</u>	<u>Q</u>	<u>Meth.</u>	<u>Std.</u>	<u>f(x)</u> <u>f(Std.)</u>	<u>Tolerance</u>	<u>Chemical Information</u>	<u>Ref.</u>	<u>f(x)</u> <u>f(H)</u>
101	70	Yb	171	$\frac{1}{2}$			+ .45		S			SH 38	
103	70	Yb	173	$\frac{5}{2}$			- .65		S			SH 38	
104	71	Lu	175	$\frac{7}{2}$			+2.9 (5)		S			KL 51	
							+2.6		S			GL 36	
105	71	Lu	176	≥ 7	[SH 38]								
					10 \pm 1 [KL 51]								
							+3.8		S			SH 38	
							4.2 (8)		S			KL 51	

TABLE 1.1 (Cont.)

<u>N</u>	<u>Z</u>	<u>Atom</u>	<u>A</u>	<u>I</u>	<u>Magnetic Moment</u>	<u>Q</u>	<u>Meth.</u>	<u>Std.</u>	<u>$\frac{f(x)}{f(Std.)}$</u>	<u>Tolerance</u>	<u>Chemical Information</u>	<u>Ref.</u>	<u>$\frac{f(x)}{f(H)}$</u>
105	72	Hf	177	$(\frac{1}{2}, \frac{3}{2})$							Predicted	BB 49	
				[,6]									
107	72	Hf	179	$(\frac{1}{2}, \frac{3}{2})$									
108	73	Ta	181	$\frac{7}{2}$									
				+2.1			S					GI 33	
				2.1			S					BN 52	
109	74	W	183	$\frac{1}{2}$									
				+ .086			S			WO ₃ enriched 90%		FO 50	
				+ .09 (2)			S	1	$\mu = .08$ corrected for nuclear size	enriched W		VR 51	
												*KP 48	

TABLE 1.1 (Cont.)

<u>N</u>	<u>Z</u>	<u>Atom</u>	<u>A</u>	<u>I</u>	<u>Magnetic Moment</u>	<u>Q</u>	<u>Meth.</u>	<u>Std.</u>	<u>f(x)</u>	<u>Tolerance</u>	<u>Chemical Information</u>	<u>Ref.</u>	<u>f(x)</u>
									<u>f(Std.)</u>				<u>f(H)</u>
110	75	Re	185	$\frac{5}{2}$									
					+3.3		S					SC 38	
					+3.143 7 (6)		R	Na ²³	.851 14	$\pm .000\ 09$	NaReO ₄ aq. and .25 NaCl + 1m. MnSO ₄	AY 51-2	.225142 (24)
112	75	Re	187	$\frac{5}{2}$									
					+3.3		S	Re ¹⁸⁵	1.011 40 1.010 69	$\pm .000\ 77$ γ 5275 $\pm .000\ 43$ γ 4889		SH 37-2	
					3.175 98 (34)		R	Na ²³	.859 87	$\pm .000\ 09$	NaReO ₄ aq. and .25 NaCl + 1m. MnSO ₄	AY 51-2	.227451 (24)
					3.175 99 (42)		R	Re ¹⁸⁵	1.010 26	$\pm .000\ 08$	See AY 51-2	AY 51-2	.227452 (31)

111 76 Os 187

TABLE 1.1 (Cont.)

<u>N</u>	<u>Z</u>	<u>Atom</u>	<u>A</u>	<u>I</u>	<u>Magnetic Moment</u>	<u>Q</u>	<u>Meth.</u>	<u>Std.</u>	<u>$\frac{f(x)}{f(Std.)}$</u>	<u>Tolerance</u>	<u>Chemical Information</u>	<u>Ref.</u>	<u>$\frac{f(x)}{f(H)}$</u>	
113	76	Os	189	$\left(\frac{1}{2}\right)$	[KD 38]									
				$\frac{3}{2}$	[MW 52]									
					+ .6 (1)		S				OsI	SU 51		
					.70 (9)		S					MW 52		
					.6		T				Predicted	RI 50		
114	77	Ir	191	$\frac{3}{2}$	[BX 50]									
					>0		S					VS 35		
					+0.16		S					MW 52		
					[- .1]		T				Predicted	BB 49		
116	77	Ir	193	$\frac{3}{2}$										
					+0.17 (3)		S	Ir ¹⁹¹	$\mu r = 1.04$	$\pm .04$		MW 52		
					[- .1]		T				Predicted	BB 49		
117	78	Pt	195	$\frac{1}{2}$										
					+ .600 34 (76)		R	Na ²³	.812 7	$\pm .000\ 1$	1m H ₂ PtCl ₆ + .5m MnCl ₂ and .2m NaCl + .2m MnSO ₄	PR 49-3	.21497 (27)	
					+ .600 37 (59)		R	Na ²³	.812 73	$\pm .000\ 08$	"	PR 51	.214982 (21)	
											SC 36			

TABLE 1.1 (Cont.)

N	Z	Atom	A	I	Magnetic Moment	Q	Meth.	Std.	<u>f(x)</u> <u>f(Std.)</u>	Tolerance	Chemical Information	Ref.	<u>f(x)</u> <u>f(H)</u>
118	79	Au	197	$\frac{3}{2}$									
					+ .195		S					ET 39	
					+ .136		S					KY 52	
					+ .16		S					VN 51	
119	80	Hg	199	$\frac{1}{2}$									
					+ .547 (2)		S					MR 40	
					.499 299 (41)	R	D ²	1.164 7		$\pm .000\ 1$	HgNO ₃ + .2m Mn(NO ₃) ₂ and 25% D ₂ O in 1.8m MnSO ₄	PR 49-3	.178 789(16)
					"	R	D ²	1.164 7		$\pm .000\ 1$	.35m Hg ₂ (NO ₃) ₂ + .2m Mn(NO ₃) ₂ and 25% D ₂ O in 1.8m MnSO ₄	PR 51	.178 789(16)
					.56							*GQ 33	
												*SH 35-4	
121	80	Hg	201	$\frac{3}{2}$								FS 51	
					- .607 (3)		S					MR 40	
												*GQ 33	
												*SH 35-4	

TABLE 1.1 (Cont.)

<u>N</u>	<u>Z</u>	<u>Atom</u>	<u>A</u>	<u>I</u>	<u>Magnetic Moment</u>	<u>Q</u>	<u>Meth.</u>	<u>Std.</u>	<u>$f(x)$</u>	<u>$f(Std.)$</u>	<u>Tolerance</u>	<u>Chemical Information</u>	<u>Ref.</u>	<u>$f(x)$</u>	<u>$f(H)$</u>
122	81	Tl	203	$\frac{1}{2}$											
					+1.45 (10)		S						SH 37		
					1.614		R	H ¹	.571 4		± .000 1	2.6m Tl(Ac) ₂ + .03m MnSO ₄	PR 49 PR 50-2	.5714 (1)	
					1.596 01 (14)		R	H ¹	.571 499		± .000 006 PE .000 05	The acetate or Formate	PH 49 PH 49-2	.571499 (50)	
					1.595 9 (13)		R	Tl ²⁰⁵	.990 3		± .000 2	2.6m Tl(Ac) ₂ + .03m MnSO ₄	PR 49	.57145 (13)	
													*GQ 33		
													*SH 37		
													*CR 49-2		

TABLE 1.1 (Cont.)

N	Z	Atom	A	I	Magnetic Moment	Q	Meth.	Std.	$\frac{f(x)}{f(Std.)}$	Tolerance	Chemical Information	Ref.	$\frac{f(x)}{f(H)}$
124	81	Tl	205	$\frac{1}{2}$	+1.611 75 (14)	R	H ¹	.577 135		$\pm .000\ 006\ PE$ $.000\ 05\ EE$		PH 49 PH 49-2	.577135 (50)
					1.611 7 (14)	R	Tl ²⁰³	1.009 86		$\pm .000\ 05\ PE\ (.01\%)$	Tl Acetate	PH 49-2	.57711 (51)
					1.611 64 (14)	R	Tl ²⁰³	1.009 83		$\pm .000\ 05\ PE\ (8s)$	Tl(C ₂ H ₃ O ₂) + Mn(Ac) ₂	SW 51	.57709 ⁶ (51)
					1.611 4 (28)	R	H ¹	.577 0		$\pm .000\ 1$		PR 49	.5770 (1)
					1.611 43 (84)	R	H ¹	.577 02		$\pm .000\ 03\ PE\ (8s)$	Tl(Ac) ₂ + MnAC ₂ and H ₂ O + FeCl ₂	SW 51	.57702 (3)
						R	Tl ²⁰³	1.009 822		$\pm .000\ 019\ (7m)$	2.6m Tl(Ac) ₂ + .03m MnSO ₄	WL 52-5	.57709 (50)
						R	Tl ²⁰³	1.009 838		$\pm 0.000\ 002$		GW 53	.57710 (50)
												*GQ 33	
												*SH 37	
												*CR 49	
125	82	Pb	207	$\frac{1}{2}$		S	1	g = .99		$\pm .04$		SA 49	.17
					+ .583 67 (14)	R	Na ²³	.790 1		$\pm .000\ 2$	1m Pb(C ₂ H ₃ O ₂) ₂ + .8m Mn(Ac ₂) and aq. NaCl + MnSO ₄	PR 49-2	.20900 (5 ³)
												*GQ 33	
												*CT 36	
												*CR 49-2	
												*SA 49	

TABLE 1.1 (Cont.)

N	Z	Atom	A	I	Magnetic Moment	Q	Meth.	Std.	$\frac{f(x)}{f(Std.)}$	Tolerance	Chemical Information	Ref.	$\frac{f(x)}{f(H)}$
126	83	Bi	209	$\frac{9}{2}$									
					$[- .4]$								
					+4.038 948 (20)	R	D ²	1.046 84		$\pm .000\ 05$	Bi(NO ₃) ₃ and D ₂ O	TI 52-2	.1606964 (78)
					4.038 79 (41)	R	D ²	1.046 8		$\pm .000\ 1$	.69m Bi(NO ₃) ₂ and 1.8m MnSO ₄ + 25% D ₂ O	PR 51	.160690 (16)
					4.038 79 (41)	R	D ²	1.046 8		$\pm .000\ 1$	See PR 51	PR 50-3	.160690 (16)
											*GQ 33		
											*WK 40		
138	89	Ac	227	$\frac{3}{2}$	[TO 51]								
140	91	Pa	231	$\frac{3}{2}$									
140	92	U	233										
143	92	U	235	$\frac{5}{2}$	[AO 47] [SB 50]								

TABLE 1.1 (Cont.)

<u>N</u>	<u>Z</u>	<u>Atom</u>	<u>A</u>	<u>I</u>	<u>Magnetic Moment</u>	<u>Q</u>	<u>Meth.</u>	<u>Std.</u>	<u>$\frac{f(x)}{f(Std.)}$</u>	<u>Tolerance</u>	<u>Chemical Information</u>	<u>Ref.</u>	<u>$\frac{f(x)}{f(H)}$</u>
144	93	Np	287	$\frac{5}{2}$									

146 95 Am 241 $\frac{5}{2}$ [FR 53]

PART 2 AUXILIARY TABLES

This portion of the Tables is included for the purpose of supplying general reference material and to show the methods and values used in determining the "standard" conversion constants for calculations in Table 1.1. Table 2.1 is a collection of the calculated best value moments. These were added as a result of the necessity for determining "standard" values of $f/f(H)$ for certain elements which are required to convert many of the measured frequency ratios to that relative to the proton. In determining these $f/f(H)$ values for Table 2.1 all reported measurements were weighted inversely as the square of their reported tolerances. It is realized that in many cases this gives an unfair weighting to those values whose tolerance was specified as estimated or actual error, but under the circumstances this was thought to be the best manner in which to weight the various results since probable error was not known for a majority of the cases. The value of the resulting magnetic moment without diamagnetic correction can be determined by multiplying the listed $f/f(H)$ by 5.58550 I, where I is the spin for the isotope under consideration. The diamagnetically corrected value for μ as tabulated in Table 2.1 is then simply $[f/f(H)] (5.58550) (I) (D)$, where D is the diamagnetic correction for the element as based on the values given in Table 3.1. The value of μ_p selected for these calculations is the same value used in Table 1.1 with the additional correction factor of 1.0000262 for diamagnetic effects. This value has been taken to be 2.79274500 nm. for purposes of the calculations and the values of Table 2.1 do not include errors in μ_p or the correction factor D. The deviation reported on the $f/f(H)$ values is the 95 per cent confidence level ($P = 0.05$) for this data. This precision, of course, does not include correction for the fact that the input data itself was not of the same P level. The column captioned n is the number of measurements used in obtaining the weighted moment value. The final de-

viation then is for the 95 per cent confidence level equal to $t \sqrt{\frac{\sum p \bar{x}^2}{(n-1)}} / p$,

where p is the weighting value used, and t the significance test factor from statistical "t" tables.

A table giving the ratios of the magnetic moments of the elements is included as Table 2.2. This table lists the ratios of the moments as reported by the various authors who have made these direct measurements, and in addition lists a value designated by WTD that has been computed from the standardized frequency ratios of Table 2.1. In many instances these WTD values bear no significance (as for Li and Tl for example) because the ratio of the two isotopes is known to a much better degree than is the ratio of either isotope to the proton. However, it does give a check on the reliability of the chosen standardized values for the isotope-to-proton ratio. A column has been left in Table 2.2 for insertion of Q ratios although no ratios have been entered at this time.

TABLE 2.1

WEIGHTED MAGNETIC MOMENTS AND STANDARDIZED FREQUENCY RATIOS

N	Z	Atom	A	I	μ diamagnetically corrected	n	ppm	f/f(H)
1	0	n	-	$\frac{1}{2}$	- 1.912 98 (42)	2	220	.685 00 (15)
0	1	H	1	$\frac{1}{2}$	+ 2.792 74 (17)	7	60	1.000 00 (6)
1	1	H	2	1	+ 0.857 407 3 (2)	7	1.6	.153 506 20 (24)
2	1	H	3	$\frac{1}{2}$	+ 2.978 84 (1)	3	15	1.066 635 (15)
1	2	He	3	$\frac{1}{2}$	- 2.127 544 (7)	1	3	.761 786 6 (23)
3	3	Li	6	1	+ 0.822 008 (22)	4	21	.147 157 6 (31)
4	3	Li	7	$\frac{3}{2}$	+ 3.256 310 (85)	5	21	.388 634 2 (81)
5	4	Be	9	$\frac{3}{2}$	- 1.177 37 (41)	3	349	.140 518 (49)
5	5	B	10	3	+ 1.800 81 (49)	3	270	.107 454 (29)
6	5	B	11	$\frac{3}{2}$	+ 2.688 52 (4)	6	12.5	.320 838 (4)
7	6	C	13	$\frac{1}{2}$	+ 0.702 34 (14)	1	199	.251 43 (5)
7	7	N	14	1	+ 0.403 71 (6)	2	153	.072 256 (11)
8	7	N	15	$\frac{1}{2}$	- 0.283 13 (12)	2	435	.101 349 ⁵ (44)
9	8	O	17	$\frac{5}{2}$	- 1.893 70 (9)	1	440	.135 566 (6)
9	9	F	18	(1)	[+ 0.8 (1)]	0		Theory
10	9	F	19	$\frac{1}{2}$	+ 2.628 50 (5)	5	20.1	.940 777 (19)
11	10	Ne	21	$\geq \frac{3}{2}$	[- 0.5 (1)]	0		Theory
11	11	Na	22	3	+ 1.746 9 (22)	1	1350	.104 19 (14)
12	11	Na	23	$\frac{3}{2}$	+ 2.217 53 (10)	4	5.8	.264 518 ² (11)
13	11	Na	24	4	+ 1.688 (5)	1		.075 55 (25)
13	12	Mg	25	$\frac{5}{2}$	- 0.855 32 (14)	1	180	.061 211 (11)
13	13	Al	26	(5)	[+ 2.8 (2)]	0		Theory
14	13	Al	27	$\frac{5}{2}$	+ 3.641 421 (30)	6	8.1	.260 569 9 (21)
15	14	Si	29	$\geq \frac{1}{2}$	(-)0.555 25 (11)	2	201	.198 65 (4)

TABLE 2.1 (Cont.)

N	Z	Atom	A	I	μ diamagnetically corrected	n	ppm	f/ τ (H)
15	15	P	30	(1)	[+ 0.6 (1)]	0		Theory
16	15	P	31	$\frac{1}{2}$	+ 1.131 62 (31)	6	273	.404 816 (110)
17	16	S	33	$\frac{3}{2}$	+ 0.643 42 (13)	1	196	.076 717 (15)
19	16	S	35	$\frac{3}{2}$	[+ 1.0 (1)]	0		Theory
17	17	Cl	34	(3)	[+ 1.4 (1)]	0		Theory
18	17	Cl	35	$\frac{3}{2}$	+ 0.821 808 (71)	5	86	.097 978 4 (84)
19	17	Cl	36	2	+ 0.9	0		Theory
20	17	Cl	37	$\frac{3}{2}$	+ 0.684 09 (6)	1	860	.081 559 (70)
19	19	K	38	(3)	[+ 1.4 (1)]	0		Theory
20	19	K	39	$\frac{3}{2}$	+ 0.391 46 (7)	1	172	.046 663 (8)
21	19	K	40	4	- 1.298 1 (4)	1	310	.058 027 (18)
22	19	K	41	$\frac{3}{2}$	+ 0.215 35 (6)	1	234	.025 670 (6)
23	19	K	42	2	- 1.137 (5)	1	4400	.101 8 (5)
23	20	Ca	43	$\frac{5}{2}$	- 1.31	1		
24	21	Sc	45	$\frac{7}{2}$	+ 4.756 31 (12)	3	21	.242 939 (5)
25	22	Ti	47	$\frac{5}{2}$	- 0.79	1		
27	22	Ti	49	$\frac{7}{2}$	- 1.104 1 (2)	1	178	.056 39 (1)
27	23	V	50	6	+ 3.347 02 (94) for NaVO ₃	3	28	.099 704 7 (28) for VOCl ₃
28	23	V	51	$\frac{7}{2}$	+ 5.147 0 (57) for NaVO ₃	3	137	.262 89 (29)
29	24	Cr	53	$\frac{3}{2}$	- 0.475	2		
30	25	Mn	55	$\frac{5}{2}$	+ 3.467 66 (14)	3	41	.247 867 (10)
31	26	Fe	57	($\frac{3}{2}$)	[- 0.66 (10)]	0		Theory
31	27	Co	58	2	+ 3.5 (3)	1		
32	27	Co	59	$\frac{7}{2}$	+ 4.648 8 (5)	1	101	.237 297 (24)

TABLE 2.1 (Cont.)

N	Z	Atom	A	I	μ diamagnetically corrected	n	ppm	f/f(H)
33	27	Co	60	5	+ 3.5 (5)	1		
33	28	Ni	61	$\frac{3}{2}$	[+ 0.10 (10)]	0		Theory
34	29	Cu	63	$\frac{3}{2}$	+ 2.226 64 (17)	5	75	.265 053 (20)
36	29	Cu	65	$\frac{3}{2}$	+ 2.384 73 (45)	6	188	.283 959 (53)
37	30	Zn	67	$\frac{5}{2}$	+ 0.875 71 (10)	1	112	.062 559 (7)
37	31	Ga	68	1				
38	31	Ga	69	$\frac{3}{2}$	+ 2.016 00 (20)	1	100	.240 003 (24)
40	31	Ga	71	$\frac{3}{2}$	+ 2.561 60 (13)	3	50	.304 957 (15)
41	32	Ge	73	$\frac{9}{2}$	[- 1.39]	0		Theory
42	33	As	75	$\frac{3}{2}$	+ 1.438 96 (16)	3	111	.171 266 (19)
43	34	Se	77	$\frac{1}{2}$	+ 0.534 058 (14)	4	26	.190 671 4 (50)
45	34	Se	79	$\frac{7}{2}$				
44	35	Br	79	$\frac{3}{2}$	+ 2.105 55 (30)	4	140	.250 547 (35)
46	35	Br	81	$\frac{3}{2}$	+ 2.269 58 (3)	5	11.2	.270 066 (3)
47	36	Kr	83	$\frac{9}{2}$	- 0.969	1		.038 46
48	37	Rb	85	$\frac{5}{2}$	+ 1.352 68 (11)	2	81	.096 552 2 (78)
49	37	Rb	86	2	(-)1.67 (40)	1		
50	37	Rb	87	$\frac{3}{2}$	+ 2.750 529 (38)	1	14	.327 213 7 (45)
49	38	Sr	87	$\frac{9}{2}$	- 1.1	1		.044
50	39	Y	89	$\frac{1}{2}$	- 0.14	1		.050
51	40	Zr	91	$\frac{5}{2}$	[- 1.1 (3)]	1	30,000	.079 (2)
52	41	Nb	93	$\frac{9}{2}$	+ 6.167 13 (35)	2	58	.244 431 (14)
53	42	Mo	95	$\frac{5}{2}$	- 0.932 70 (18)	1	196	.066 533 (13)
55	42	Mo	97	$\frac{5}{2}$	- 0.952 29 (10)	1	103	.067 930 (7)
56	43	Tc	99	$\frac{9}{2}$	+ 5.680 48 (35)	1	6.3	.225 082 6 (14)
55	44	Ru	99	$\frac{5}{2}$				

TABLE 2.1 (Cont.)

N	Z	Atom	A	I	μ diamagnetically corrected	n	ppm	f/f(H)
57	44	Ru	101	$\frac{5}{2}$				
58	45	Rh	103	$\frac{1}{2}$	(-0.11	1	.040	
59	46	Pd	105	$\frac{5}{2}$	[-(-0.6)]	1	.043	
60	47	Ag	107	$\frac{1}{2}$	- 0.111 (8)	1	.039	
62	47	Ag	109	$\frac{1}{2}$	- 0.129 (8)	1	.046	
63	48	Cd	111	$\frac{1}{2}$	- 0.594 99 (8)	1	142	.212 04 (3)
65	48	Cd	113	$\frac{1}{2}$	- 0.622 43 (8)	1	136	.221 82 (3)
64	49	In	113	$\frac{9}{2}$	+ 5.523 17 (54)	1	97	.218 669 (21)
66	49	In	115	$\frac{9}{2}$	+ 5.534 41 (66)	5	119	.219 118 (26)
65	50	Sn	115	$\frac{1}{2}$	- 0.917 798 (76)	1	83	.326 997 (27)
67	50	Sn	117	$\frac{1}{2}$	- 0.999 90 (19)	2	814	.356 25 (29)
69	50	Sn	119	$\frac{1}{2}$	- 1.046 11 (84)	3	81	.372 71 (3)
70	51	Sb	121	$\frac{5}{2}$	+ 3.358 92 (19)	3	55	.239 315 (13)
72	51	Sb	123	$\frac{7}{2}$	+ 2.546 53 (3)	3	11.6	.129 595 (15)
73	51	Sb	124	(3)				
71	52	Te	123	$\frac{1}{2}$	- 0.735 87 (23)	1	305	.262 097 (80)
73	52	Te	125	$\frac{1}{2}$	- 0.887 16 (26)	1	300	.315 985 (94)
73	53	I	126	2				
74	53	I	127	$\frac{5}{2}$	+ 2.808 97 (23)	5	80	.200 076 (16)
76	53	I	129	$\frac{7}{2}$	+ 2.617 266 (12)	2	4.5	.133 157 5 (6)
78	53	I	131	$\frac{9}{2}$				
75	54	Xe	129	$\frac{1}{2}$	- 0.776 756 (53)	2	69	.276 595 (19)
77	54	Xe	131	$\frac{3}{2}$	+ 0.708	1		.821
76	55	Cs	131		+ 3.48 (4)	1		
78	55	Cs	133	$\frac{7}{2}$	+ 2.578 93 (3)	4	11.5	.131 170 9 (15)
79	55	Cs	134	(4)	+ 2.95 (1)	1	3780	.132 5
80	55	Cs	135	$\frac{1}{2}$	+ 2.738 2 (19)	2	3600	.139 27

TABLE 2.1 (Cont.)

N	Z	Atom	A	I	μ diamagnetically corrected	n	ppm	f/f(H)
82	55	Cs	137	$\frac{7}{2}$	+ 2.850 2 (25)	2	3460	.145 0
79	56	Ba	135	$\frac{3}{2}$	+ 0.835 5 (24)	1		
81	56	Ba	137	$\frac{3}{2}$	+ 0.932 4 (27)	1		
81	57	La	138					
82	57	La	139	$\frac{7}{2}$	+ 2.778 07 (61)	3	219	.141 260 (31)
82	59	Pr	141	$\frac{5}{2}$	+ 3.9 (3)	1		
83	60	Nd	143	$\frac{7}{2}$	- 1.0 (2)	1		
85	60	Nd	145	$\frac{7}{2}$	- 0.62 (9)	1		
86	61	Pm	147	$\frac{7}{2}$				
85	62	Sm	147	$\frac{7}{2}$	(-)0.68 (1)	1		
87	62	Sm	149	$\frac{7}{2}$	(-)0.55 (1)	1		
88	63	Eu	151	$\frac{5}{2}$	+ 3.4	1		
90	63	Eu	153	$\frac{5}{2}$	+ 1.5	1		
91	64	Gd	155	($\frac{3}{2}, \frac{7}{2}, \frac{9}{2}$)	+ 0.3 (2)	1		
93	64	Gd	157	($\frac{3}{2}, \frac{7}{2}, \frac{9}{2}$)	+ 0.3 (2)	1		
94	65	Tb	159	$\frac{3}{2}$	[+ .7 (3)]	0		Theory
95	66	Dy	161	($\frac{7}{2}, \frac{9}{2}$)				
97	66	Dy	163	($\frac{7}{2}, \frac{9}{2}$)				
98	67	Ho	165	$\frac{7}{2}$	[+ 3.0 (5)]	0		Theory
99	68	Er	167	$\frac{7}{2}$				
100	69	Tm	169	$\frac{1}{2}$	[+ .8 or -.15]	0		Theory
101	70	Yb	171	$\frac{1}{2}$	+ 0.45	1		
103	70	Yb	173	$\frac{5}{2}$	- 0.66	1		
104	71	Lu	175	$\frac{7}{2}$	+ 2.9 (5)	1		
105	71	Lu	176	(≥ 7)	+ 4.2 (8)	1		

TABLE 2.1 (Cont.)

N	Z	Atom	A	I	μ diamagnetically corrected	n	ppm	f/f(H)
105	72	Hf	177	$(\frac{1}{2}, \frac{3}{2})$	[+ 0.6]	0		Theory
107	72	Hf	179	$(\frac{1}{2}, \frac{3}{2})$				
108	73	Ta	181	$\frac{7}{2}$	+ 2.1	1		
109	74	W	183	$\frac{1}{2}$	+ 0.087 (2)	1		
110	75	Re	185	$\frac{5}{2}$	+ 3.171 56 (34)	1	107	.225 142 (24)
112	75	Re	187	$\frac{5}{2}$	+ 3.175 91 (34)	1	107	.225 451 (24)
111	76	Os	187					
113	76	Os	189	$(\frac{1}{2}, \frac{3}{2})$	+ 0.71 (1)	1		
114	77	Ir	191	$\frac{3}{2}$	[- 0.1]	0		Theory
116	77	Ir	193	$\frac{3}{2}$	+ 0.17 (3)	1		
117	78	Pt	195	$\frac{1}{2}$	+ 0.605 96 (21)	1	346	.214 978 (74)
118	79	Au	197	$\frac{3}{2}$	+ 0.16	1		
119	80	Hg	199	$\frac{1}{2}$	+ 0.504 117 (41)	1		.178 789 (16)
121	80	Hg	201	$\frac{3}{2}$	- 0.613 (3)			
122	81	Tl	203	$\frac{1}{2}$	+ 1.611 6 (14)	2	875	.571 48 (50)
124	81	Tl	205	$\frac{1}{2}$	+ 1.627 34 (42)	6	87	.577 05 (5)
125	82	Pb	207	$\frac{1}{2}$	+ 0.589 43 (14)	1		.209 00 (5)
126	83	Bi	209	$\frac{9}{2}$	+ 4.079 70 (81)	2		.160 695 (32)
138	89	Ac	227	$\frac{3}{2}$				
140	91	Pa	231	$\frac{3}{2}$				
141	92	U	233					
143	92	U	235	$\frac{5}{2}$				
144	93	Np	237	$\frac{5}{2}$				
146	95	Am	241	$\frac{5}{2}$				

TABLE 2.2
MAGNETIC MOMENT RATIOS

Isotopes	μ ratio	Reference	Q ratio
${}_1^{\text{H}}{}^2 / {}_1^{\text{H}}{}^1$	0.307 012 40 (48) See Table 1.1	WT D*	
${}_1^{\text{H}}{}^3 / {}_1^{\text{H}}{}^1$	1.066 635 (34) 1.066 66 (10) 1.066 636 (10)	WT D AN 47 BL 47-2	
${}_3^{\text{Li}}{}^7 / {}_3^{\text{Li}}{}^6$	3.961 45 (14) 3.961 41 (7) 3.961 37 (2) 3.961 366 1 (75)	WT D KU 49-4 WA 51 AD 51-2	
${}_5^{\text{B}}{}^{11} / {}_5^{\text{B}}{}^{10}$	1.492 91 (40) 1.493 07 (46)	WT D BI 49	
${}_7^{\text{N}}{}^{15} / {}_7^{\text{N}}{}^{14}$	-0.701 32 (39) -0.701 30 (50) -0.701 35 (50)	WT D PR 51 PR 51	
${}_{11}^{\text{Na}}{}^{23} / {}_{11}^{\text{Na}}{}^{22}$	1.269 40 (14)	WT D	
${}_{17}^{\text{Cl}}{}^{35} / {}_{17}^{\text{Cl}}{}^{35}$	0.832 42 (74) 0.832 36 (7) 0.832 43 (7) 0.832 445 (42)	WT D PR 50 WA 51 TI 52-2	
${}_{19}^{\text{K}}{}^{40} / {}_{19}^{\text{K}}{}^{39}$	-0.331 61 (6)	WT D	
${}_{22}^{\text{Ti}}{}^{49} / {}_{22}^{\text{Ti}}{}^{47}$	1.000 35 (3)	WT D	
${}_{23}^{\text{V}}{}^{51} / {}_{23}^{\text{V}}{}^{50}$	1.538 07 (24)	WT D	
${}_{29}^{\text{Cu}}{}^{65} / {}_{29}^{\text{Cu}}{}^{63}$	1.071 33 (24) 1.071 1 (2) 1.071 78 (5)	WT D PO 48 SW 51	
${}_{31}^{\text{Ga}}{}^{71} / {}_{31}^{\text{Ga}}{}^{69}$	1.270 64 (24) 1.270 59 1.270 1 (4)	WT D BG 48 PO 48-2	
${}_{35}^{\text{Br}}{}^{81} / {}_{35}^{\text{Br}}{}^{79}$	1.077 91 (16) 1.077 8 (3) 1.077 75 (5) 1.077 906 (18)	WT D PO 47 SW 51 WL 52-5	

*All WTD ratios have been computed from $f(x)/f(H)$ ratios of Table 2.1

TABLE 2.2 (Cont.)

Isotopes	μ ratio	Reference	Q ratio
$^{87}\text{Rb}^{87}/^{87}\text{Rb}^{85}$	2.033 39 (19) 2.033 380 (28) 2.033 390 5 (75)	WTD AD 51, BI 51 YA 51	
$^{42}\text{Mo}^{97}/^{42}\text{Mo}^{95}$	1.021 0 (24) 1.021 0 (10)	WTD PR 51	
$^{44}\text{Ru}^{101}/^{44}\text{Ru}^{99}$	1.09 (3)	GF 52	
$^{47}\text{Ag}^{109}/^{47}\text{Ag}^{107}$	1.16 (10)	WTD	
$^{48}\text{Cd}^{113}/^{48}\text{Cd}^{111}$	1.046 1 (3) 1.046 1 (1)	WTD PR 50-2	
$^{49}\text{In}^{115}/^{49}\text{In}^{113}$	1.002 05 (15) 1.002 24 (10) 1.002 1 (1) 1.002 13 (4)	WTD MD 50 PR 51 TI 52-2	
$^{50}\text{Sn}^{119}/^{50}\text{Sn}^{117}$	1.046 2 (9) 1.046 5 (3)	WTD PR 50-2	
$^{50}\text{Sn}^{117}/^{50}\text{Sn}^{115}$	1.089 46 (90) 1.089 47 (10)	WTD PR 50-2	
$^{51}\text{Sb}^{123}/^{51}\text{Sb}^{121}$	0.758 135 (46)	WTD	
$^{52}\text{Te}^{125}/^{52}\text{Te}^{123}$	1.205 6 (5) 1.208 (60) 1.136 1.186 (7)	WTD MA 49-2 FO 50 RM 52	
$^{53}\text{I}^{129}/^{53}\text{I}^{127}$	0.931 748 (75)	WTD	
$^{54}\text{Xe}^{131}/^{54}\text{Xe}^{129}$	-0.911 -0.901 -0.884 (4)	WTD KP 34 BH 52	
$^{55}\text{Cs}^{135}/^{55}\text{Cs}^{133}$	1.061 7 (55)	WTD	
$^{55}\text{Cs}^{137}/^{55}\text{Cs}^{133}$	1.105 4 (55)	WTD	
$^{56}\text{Ba}^{137}/^{56}\text{Ba}^{135}$	1.115 98 (48) 1.118 4	WTD HH 41	
$^{60}\text{Nd}^{145}/^{60}\text{Nd}^{143}$	0.62 (12) 0.625 (23) 0.621 (4)	WTD MW 51 BE 51-2 BE 50	

TABLE 2.2 (Cont.)

Isotopes	μ ratio	Reference	Q ratio
$^{62}\text{Sm}^{149}/^{62}\text{Sm}^{147}$	0.818 3 (52)	BO 52	
$^{63}\text{Eu}^{155}/^{63}\text{Eu}^{153}$	0.44	WTD	
	0.45	SH 35-2	
$^{70}\text{Yb}^{173}/^{70}\text{Yb}^{171}$	-1.47	WTD	
$^{71}\text{Lu}^{176}/^{71}\text{Lu}^{175}$	1.45	WTD	
$^{75}\text{Re}^{187}/^{75}\text{Re}^{185}$	1.001 37 (15)	WTD	
	1.010 26 (8)	AY 51-2	
	1.011 40 (77)	SH 37-2	
	1.010 69 (43)	SH 37-2	
$^{77}\text{Ir}^{193}/^{77}\text{Ir}^{191}$	1.04 (4)	MW 52	
$^{80}\text{Hg}^{201}/^{80}\text{Hg}^{199}$	-1.215 9 (60)	WTD	
$^{81}\text{Tl}^{205}/^{81}\text{Tl}^{203}$	1.009 74 (51)	WTD	
	1.009 86 (5)	PH 49-2	
	1.009 83 (5)	SW 51	
	1.009 822 (19)	WL 52-5	
	1.009 7 (2)	PR 49	
	1.009 838 (2)	GW 53	

Requests have been received to list a value for the resonance frequency at a specified field strength (10,000 gauss for example) for each element. Because of space limitations this could not be included in Table 1.1. However, to provide a rapid method of approximating the field-frequency relationship for each element, a graph of these parameters as a function of the gyromagnetic ratio has been included as Figure 2.1. Gyromagnetic ratios from 0.15 to 5.58 are included and lines have been plotted for the most used nuclei such as H, D, F, Na, and N¹⁴; others can be added to suit the individual needs.

As a means for comparing visually the data of Table 2.1 graphs showing the measured values of μ and I for both odd proton and odd neutron nuclei are included along with lines showing the Schmidt and Dirac limits. A similar graph occurred in publication (KL 52) during the composing of this report but it was deemed worthwhile to reproduce these again within this report with only minor changes and additions. The μ -I plot for odd proton nuclei appears as Figure 2.2 and the μ -I plot for odd neutron nuclei is Figure 2.3.

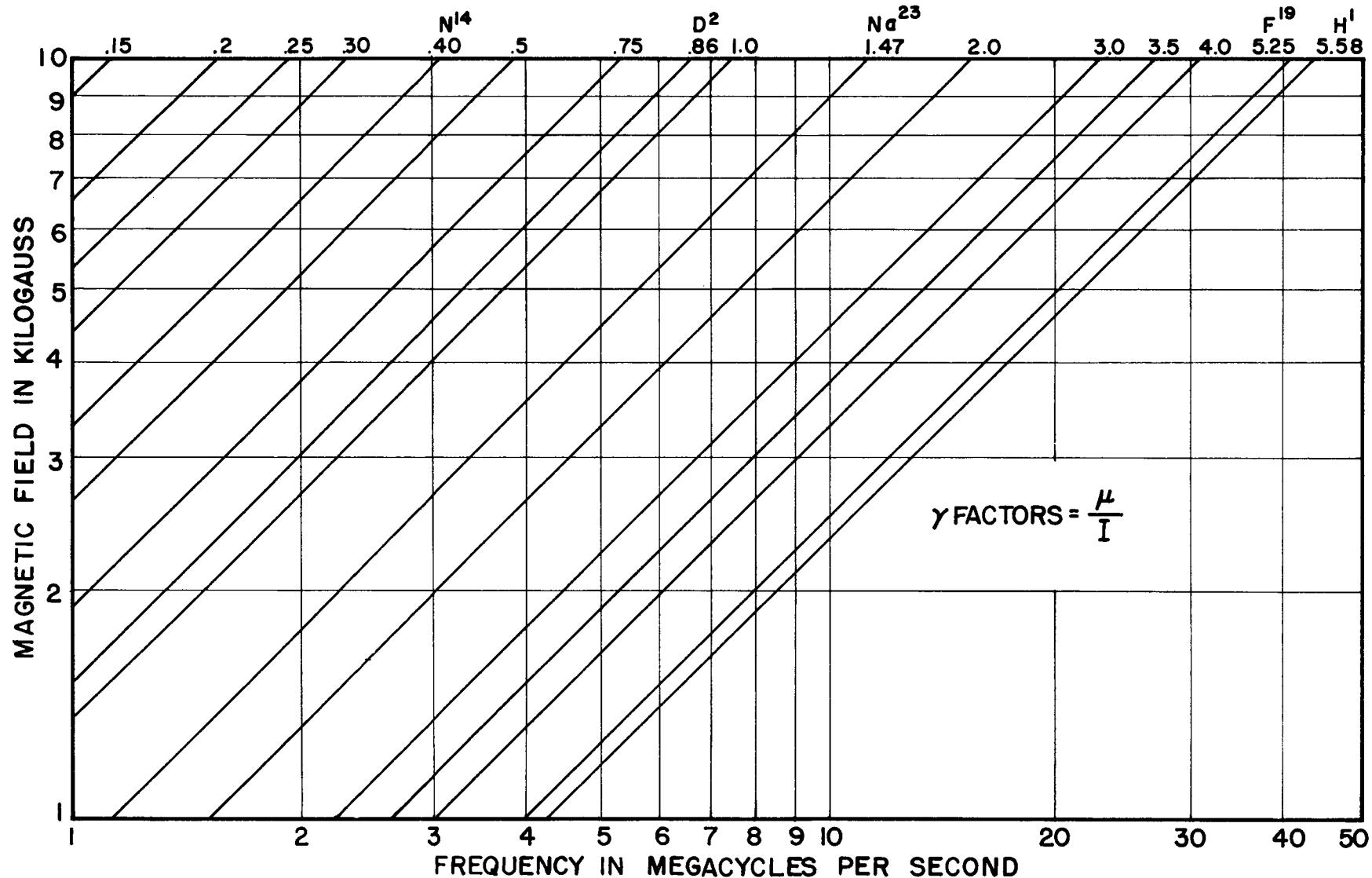


FIGURE 2.1 GYROMAGNETIC FACTOR-FIELD DETERMINATION CHART

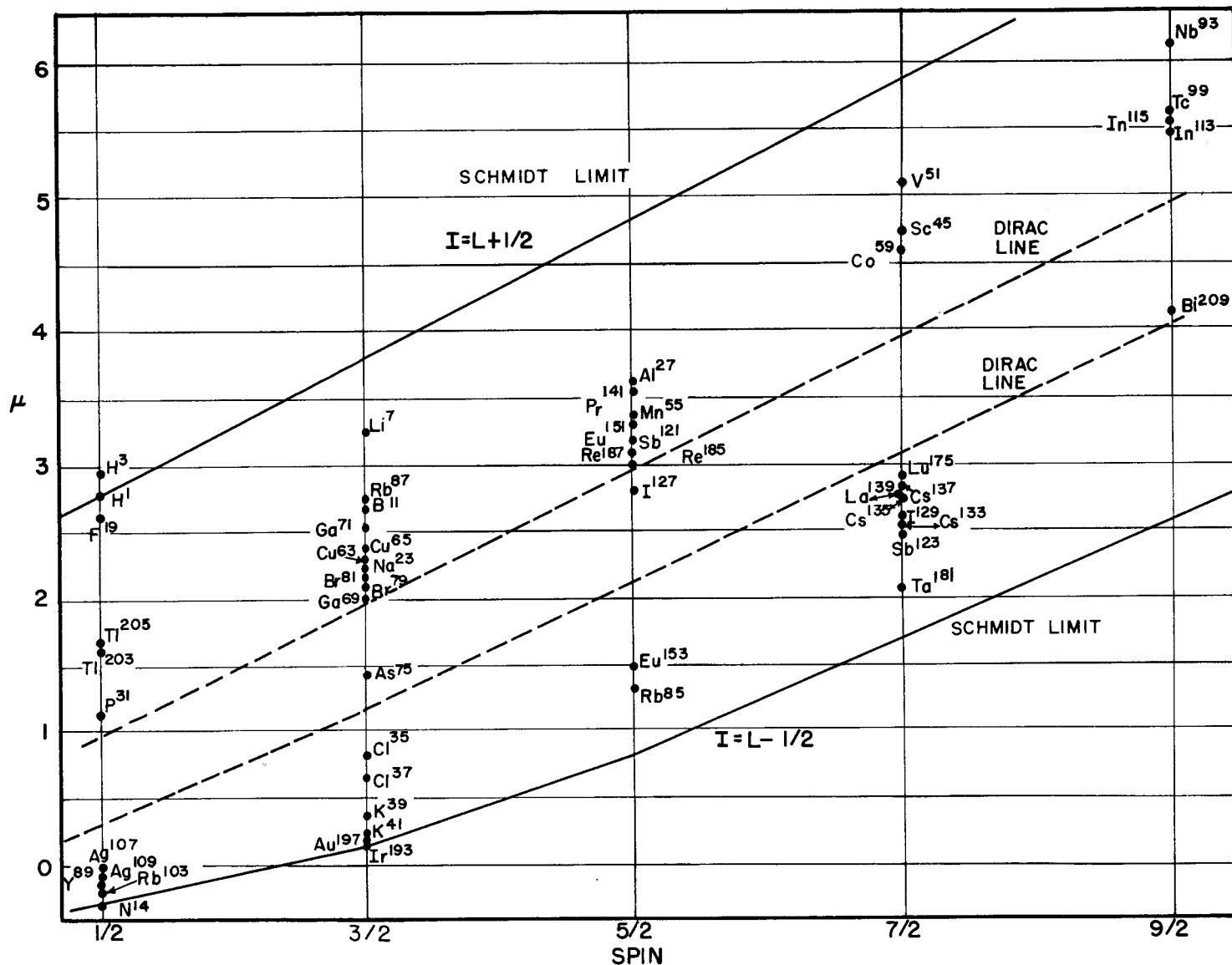


FIGURE 2.2 μ -I PLOT FOR ODD PROTON NUCLEI

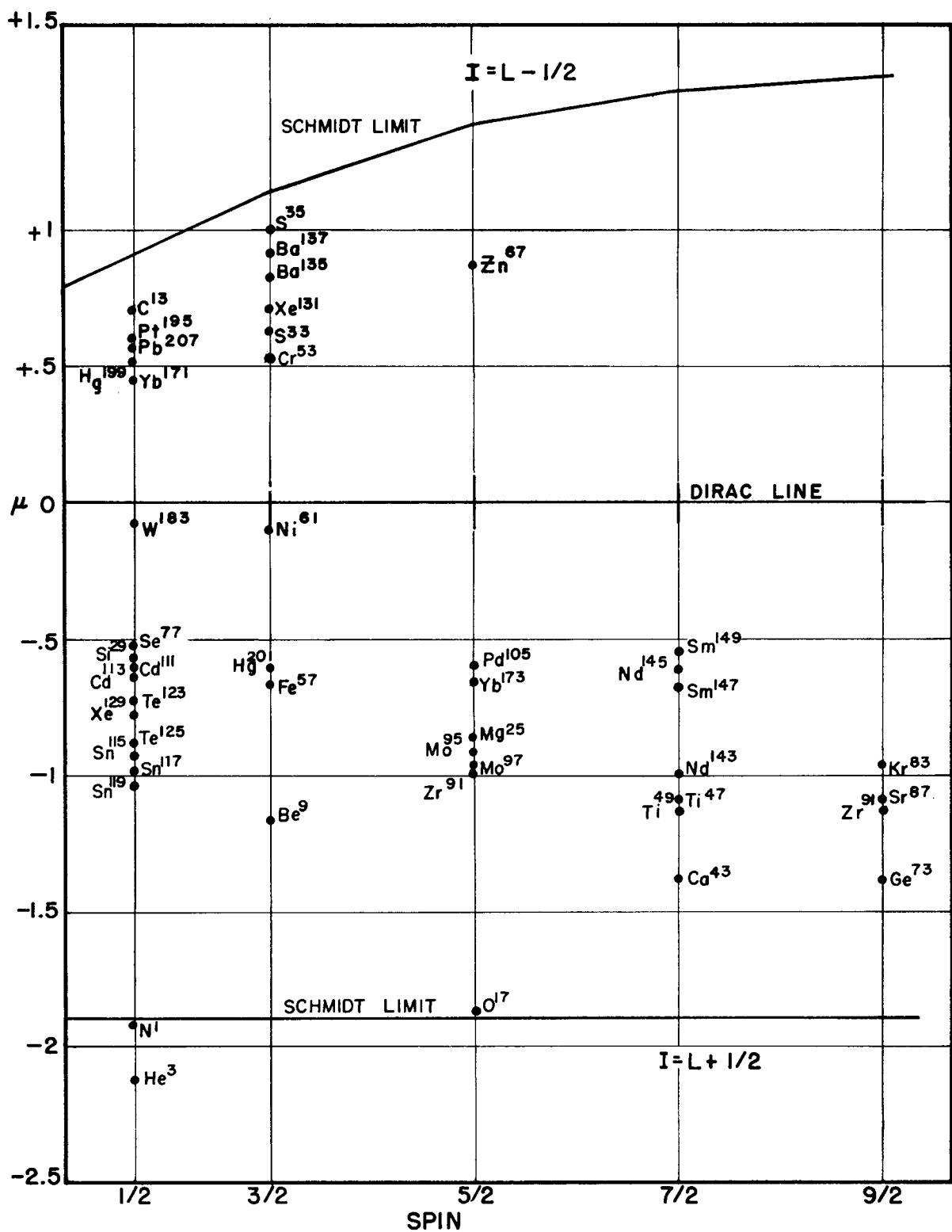


FIGURE 2.3 PLOT FOR ODD NEUTRON NUCLEI

A value for the magnetic moment of the proton was selected to permit calculation of the magnetic moments of other nuclides. At that time the best published value for the proton moment was that of DuMond and Cohen (DU 52). No output data for the proton was reported and their input data was the weighted mean of SO 50 and BL 50. This value is $2.792745 \pm 0.000055 (\sigma)$ nm. For our calculations a weighting was made for TA 49, GD 49, SO 50, JR 51, LM 51, and TH 50-2 with a resulting proton moment of 2.792743 ± 0.00003 (PE) nm. This is in essential agreement with the data of DuMond and Cohen.

The values used throughout these Tables are:

Proton Magnetic Moment (without diamagnetic correction) = $2.79267000\dots$ nm.

Proton Diamagnetic Correction Factor = 1.0000262

Proton Magnetic Moment (with diamagnetic correction) = $2.79274\dots$ nm.

The resulting calculations of Table 1.1 and Table 2.1 assume no errors in these values.

Since the initial calculations were performed, a more recent tabulation of the atomic constants has been prepared by DuMond and Cohen (DU 52-2). They have reported a "least squares" value for the diamagnetically corrected proton moment of $2.79277 \pm 0.00006 (\sigma)$ nm. Using the above correction factor, the magnetic moment without diamagnetic correction is found to be 2.79270 ± 0.00006 nm. We have therefore not changed the calculated values appearing in the tables, since the originally assigned value for the proton moment is within the limits of the DuMond and Cohen figure.

PART 3 NUCLEAR MAGNETIC SHIELDING

The nuclear magnetic resonances of an element in various compounds have been observed to occur at different values of the applied magnetic field. This section of the Tables was conceived for the purpose of collecting together as much of the experimental information on chemical shift effects as is available at this time (Jan. 1, 1953). Omissions are possible because of the widespread reporting of such information in the various physics, chemistry, and scientific journals. It is hoped that no major contributions have been overlooked. Since many of the published data lose significance and meaning in an abstracted listing such as this, only a few comments on the various theories offered have been included here, thus leaving the reader to peruse the original articles for further details.

The magnetic field at the nucleus of an atom differs from the externally applied field. Ramsey (RN 50-2, RN 50-3, RN 52), Gutowsky (GW 51), Dickinson (DN 51), and others have given theories in justification of the observed resonance shifts.

Dickinson (DN 50) has calculated the internal diamagnetic field for a neutral atom or monatomic ion using the Hartree approximation in the Lamb shielding expression. In Table 3.1, this correction is given in terms of the ratio of induced field to external field $H'(O)/H$ for each value of Z with an estimated accuracy of 5 per cent. This calculated correction is usually applied to correct the computed magnetic moment. In cases where the nucleus was not in the neutral atom or monatomic ionic state, this correction is in some error and can therefore be used only as a first approximation to the true correction. Ramsey (RN 50-2, RN 50-3) has shown that σ , the expression for the magnetic shielding field, is composed of two parts. The first a simple term that is similar to the diamagnetic correction developed by Lamb for atoms. The second is a term arising from second order induced paramagnetism. He further (RN 52-1) developed an expression for the nuclear shielding in solids and molecules and discussed the temperature dependent magnetic shielding which has been observed experimentally by others. Under certain circumstances, where a large percentage of the electrons may be influenced by chemical bond, the second order paramagnetism term can be quite large. For linear molecules, the second term in Ramsey's expression is shown to be directly related to the experimentally measurable spin-rotational magnetic interaction constant of the molecule.

Gutowsky and McCall (GW 51-2), and others have observed resonance fine structure in liquids and suggested that liquids having a composition of type $A \cdot X_n$ with structurally identical X's should have a splitting of the A

TABLE 3.1
INTERNAL DIAMAGNETIC CORRECTION FOR NEUTRAL ATOMS*

Z	H'(O)/H %	Z	H'(O)/H %	Z	H'(O)/H %
1	0.0018	32	0.273	63	0.693
2	0.0060	33	0.285	64	0.709
3	0.0101	34	0.296	65	0.724
4	0.0149	35	0.308	66	0.740
5	0.0199	36	0.321	67	0.756
6	0.0261	37	0.333	68	0.772
7	0.0325	38	0.345	69	0.788
8	0.0395	39	0.358	70	0.804
9	0.0464	40	0.371	71	0.820
10	0.0547	41	0.384	72	0.837
11	0.0629	42	0.397	73	0.853
12	0.0710	43	0.411	74	0.869
13	0.0795	44	0.425	75	0.885
14	0.0881	45	0.438	76	0.901
15	0.0970	46	0.452	77	0.917
16	0.106	47	0.465	78	0.933
17	0.115	48	0.478	79	0.949
18	0.124	49	0.491	80	0.965
19	0.133	50	0.504	81	0.982
20	0.142	51	0.517	82	0.998
21	0.151	52	0.531	83	1.01
22	0.161	53	0.545	84	1.03
23	0.171	54	0.559	85	1.05
24	0.181	55	0.573	86	1.06
25	0.191	56	0.587	87	1.08
26	0.202	57	0.602	88	1.10
27	0.214	58	0.616	89	1.11
28	0.226	59	0.631	90	1.13
29	0.238	60	0.647	91	1.15
30	0.249	61	0.662	92	1.16
31	0.261	62	0.678		

*This table is that presented by W. C. Dickinson and appears with a detailed discussion in Physical Review 80, 567 (1950). Values are believed to be valid to about 5% except perhaps for the heaviest elements.

magnetic resonance into $(2nI_x + 1)$ equally spaced components with relative intensities given by the binomial coefficients. This is illustrated by the P^{31} resonance in some liquid phosphorus halides $POCl \cdot F_2$ and $POCl_2 \cdot F$ where $X = F^{19}$, $I_x = \frac{1}{2}$ and $n = 2$ and 1 respectively, thereby giving 3 components of ratio 1:2:1 for $POCl \cdot F_2$ and 2 equally spaced values for $POCl_2 \cdot F$. Observations by Proctor (PR 51) and Dharmatti (DH 52-3) for the resonance of antimony in antimony hexafluoride ion $[SbF_6]^-$, agree with this proposal where 7 lines were observed and 7 predicted. ($A = Sb$, $X_n = F_6$, $2nI_x + 1 = 7$).

Several individuals have reported strange observational phenomena in the resonances of nuclides in various compounds. E. L. Hahn (HA 50) has reported observation of a modulation or slow beat phenomenon in the spin echo envelope. A discussion of the transient nutations in nuclear magnetic resonance has been made by Torrey (TR 49). E. L. Hahn (HA 50) has used this transient effect in conjunction with a pulsed rf system to obtain nuclear relaxation times. He has also discussed the problem of self diffusion as regards its effect on the relaxation time measurement. Gutowsky (GW 51-6), McCall, and Slichter have proposed a theory involving an interaction of the form $A\bar{\mu}_1\bar{\mu}_2$ to explain the multiple resonances in certain compounds by coupling among the nuclear magnetic dipoles in the molecules. They have discussed their objections to the proposed theories accounting for this multiple splitting by rotational hinderance and second-order magnetic dipole interactions.

The effects of electronic paramagnetism on nuclear magnetic resonance frequencies in metals have been discussed by Korringa (KR 50), Abell (AB 50), Knight (KG 51, KG 52), Gutowsky (GW 52-2) and others. In addition Gutowsky has made measurements on the temperature dependence of the resonance line width in several metals and discusses the relation of line widths and second moments of the resonance with a comparison of calculated and measured values. A comparison of the results of the various authors is given in Table 3.1a and Figures 3.3 and 3.3b.

This compilation in no way has attempted to be exhaustive in listing information concerning the phenomena connected with the nuclear resonances. It has attempted to list only a few of the significant contributions to guide interested individuals in pursuit of this information. Some work not appearing in publications has been performed by the Physics Department staff at the University of Wyoming. This information is available in the form of quarterly progress reports, upon request to them.

A bibliography of papers on nuclear magnetic resonance covering the period 1942 to 1951 and bearing the title, "List of Papers on Nuclear Induction Studies, with Particular Reference to Nuclear and Paramagnetic Absorption," has been prepared by the Information Office, Atomic Energy Research Establishment, Harwell, Berks, England and was issued in June 1951 under their report number AERE Inf/Bib-75. The material listed therein is taken from Science Abstracts A through that period.

An attempt has been made to collect together information that has been published prior to January 1953 dealing with the shift due to chemical effects. This is listed in tabular form for each element and plotted graphically as a function of field change for each compound. The highest value of the applied magnetic field has been chosen as an arbitrary reference point and the shielding calculated in terms of $\Delta H/H$ per cent for the other compounds.

TABLE 3.1a
MAGNETIC SHIELDING EFFECTS IN METALS

Element	$\Delta H/H$ for specified reference in per cent				
	KG 50	TW 50	AB 52	GW 52-2	WL 52-3
Li 7	0.036	0.04	0.02	0.0261 ± 0.0002 (LiNO ₃ in NH ₃)	x
Be 9	x	<0.002	x	x	x
Na 23	0.104 (NaCl)	0.10	x	0.112 ± 0.001 (NaOH)	x
Al 27	0.159 (AlCl ₃)	0.16	x	0.161 ± 0.001 (AlCl ₃)	x
V 51	x	x	x	x	0.61 (NaVO ₃)
Cu 63	0.229 (CuCl)	0.23	x	0.237 ± 0.001 (CuBr)	0.2 (CuCl)
Cu 65	0.232 (CuCl)	x	x	0.235 ± 0.002 (CuBr)	0.2 (CuCl)
Ga 71	0.449 (GaCl ₃)	0.44	x	0.449 ± 0.004 (GaCl ₃)	x
Rb 85	x	x	0.60	0.650 ± 0.005 (RbOH)	x
Rb 87	x	x	x	0.653 ± 0.002 (RbOH)	x
Cs 133	x	1.2	x	x	x
Pb 207	x				

The Proton - 1H

Perhaps more is known about the proton than any other nucleus. As previously pointed out, Ramsey (RN 50-2) and others have discussed the theoretical shielding effects for the proton. On the basis of these considerations, he has determined the shielding correction for molecular H_2 using Nordsiecks (NO 40) wave function and Anderson's (AN 48) value of 3.24×10^{-5} for the Lamb type term to be $\sigma = 2.68 \times 10^{-5}$. This can be compared with the Lamb formula calculation applied to the hydrogen atom (Dickinson, DN 50) of $\sigma = 1.8 \times 10^{-5}$ or to the value determined by Hylleraas and Skavlem (HY 50) where $\sigma = 3.16 \times 10^{-5}$.

G. F. Newell (NE 50) calculated the first term of Ramsey's equation using his value for $1/r$, the average electron-nucleus reciprocal distance taken over the electron distribution of the ground state of H_2 . The average value for the second term is calculated to be $-0.55 \times 10^{-5} \pm 5\%$ giving $\sigma = (2.66 \pm 0.03) \times 10^{-5}$. Ramsey's value for the second term is $(-0.56 \pm 0.01) \times 10^{-5}$.

Several direct measurements of the proton shielding have been made. These are described in the following paragraphs:

Thomas (TH 50) has measured the ratio of the proton resonance in H_2 gas, oil, and water and has used Ramsey's correction factor for H_2 gas to determine the correction for oil and water. The results are given in Table 3.2. The value for μ_p without diamagnetic correction should be corrected by multiplying by 1 plus this factor.

TABLE 3.2

CORRECTION FACTOR FOR PROTON RESONANCE IN OIL AND WATER*

Ratio	$\Delta H/H$	Correction Factor
H_2 gas to oil	1.6×10^{-6}	28.4×10^{-6}
H_2 gas to water	-0.6×10^{-6}	26.2×10^{-6}

*H. Thomas, Phys. Rev. 80, 901 (1950)

Gutowsky and McClure (GW 51-3) have measured the proton shift in mineral oil, distilled water, and H_2 gas. A diamagnetic correction for the susceptibility based on $[(4\pi/3 - a) k H_0]$ was used; where in their case $a = 2\pi$, $k = -0.70 \times 10^{-6}$ for H_2O and $(-0.65 \pm 0.05) \times 10^{-6}$ for oil. The results appear in Table 3.3.

TABLE 3.3

MAGNETIC SHIELDING OF PROTON RESONANCE IN H₂, H₂O AND
MINERAL OIL AT 27.1 Mc (~6365 GAUSS). THE H₂ RESONANCE
APPEARS AT THE LOWEST VALUE OF APPLIED FIELD*

Sample	Difference in applied Field (gauss) corrected for diamagnetism	Fractional effect corrected for diamagnetism	Fractional effect corrected for "infinite cylinder"
Mineral oil (Nujol)	0.0235 ± 0.0020	(3.7 ± 0.3) × 10 ⁻⁶	(2.3 ± 0.15) × 10 ⁻⁶
H ₂ O (distilled)	0.0020 ± 0.0020	(0.3 ± 0.3) × 10 ⁻⁶	(-1.2 ± 0.15) × 10 ⁻⁶
H ₂ (gas, 30 atm)	0.0000 ± 0.0020	(0.0 ± 0.3) × 10 ⁻⁶	(0.0 ± 0.3) × 10 ⁻⁶

*Gutowsky and McClure, Phys. Rev. 81, 276 (1951)

Lindström (LM 50, LM 51) has reported the ratio of moments for the proton in paraffin oil to that in H₂O to be 1.0000041 ± .0000030. In a later publication (LM 51-2) he gives a lowered tolerance figure of ± .0000015. The fractional field difference thus being (4.1 ± 1.5) × 10⁻⁶.

W. C. Dickinson (DN 51) has shown the effect of the dependence of the concentration of paramagnetic ions on the proton resonance as well as the effects of sample shape. These are reproduced from his article as Figures 3.1 and 3.2.

Gutowsky and Hoffman (GW 51) have measured the shifts in the proton resonance in various compounds. The data as published in Table IV of GW 51 is reproduced in our Table 3.4. The value for the magnetic shielding of the proton is given on the basis of a theoretical shielding constant for H₂ of 2.66 × 10⁻⁵ (NE 50). It is pointed out that the calculations of Newell give the diamagnetic term a value of 3.21 × 10⁻⁵ and the second order paramagnetic term as -0.55 × 10⁻⁵. The observed shielding values range from 2.31 × 10⁻⁵ in HF to 4.23 × 10⁻⁵ in HI, requiring that the maximum electrostatic potential term (diamagnetic term) be at least 4.23 × 10⁻⁵. Since all observed proton shielding values are positive, it appears that the diamagnetic term is larger than the paramagnetic term in these compounds.

Arnold and Packard (AP 51) have observed a temperature dependent shift in the proton signals of the OH group not observed in CH₂ and CH₃ groups. Liddel and Ramsey (LD 51) have suggested a mechanism for this temperature dependence if there are alternative molecular states whose energy separation is of the order of kT. One mechanism for the production of such states is the process of association. Association by the hydrogen bond involving the OH group should cause a different proton shielding in the associated and unassociated states. Arnold and Packard have measured

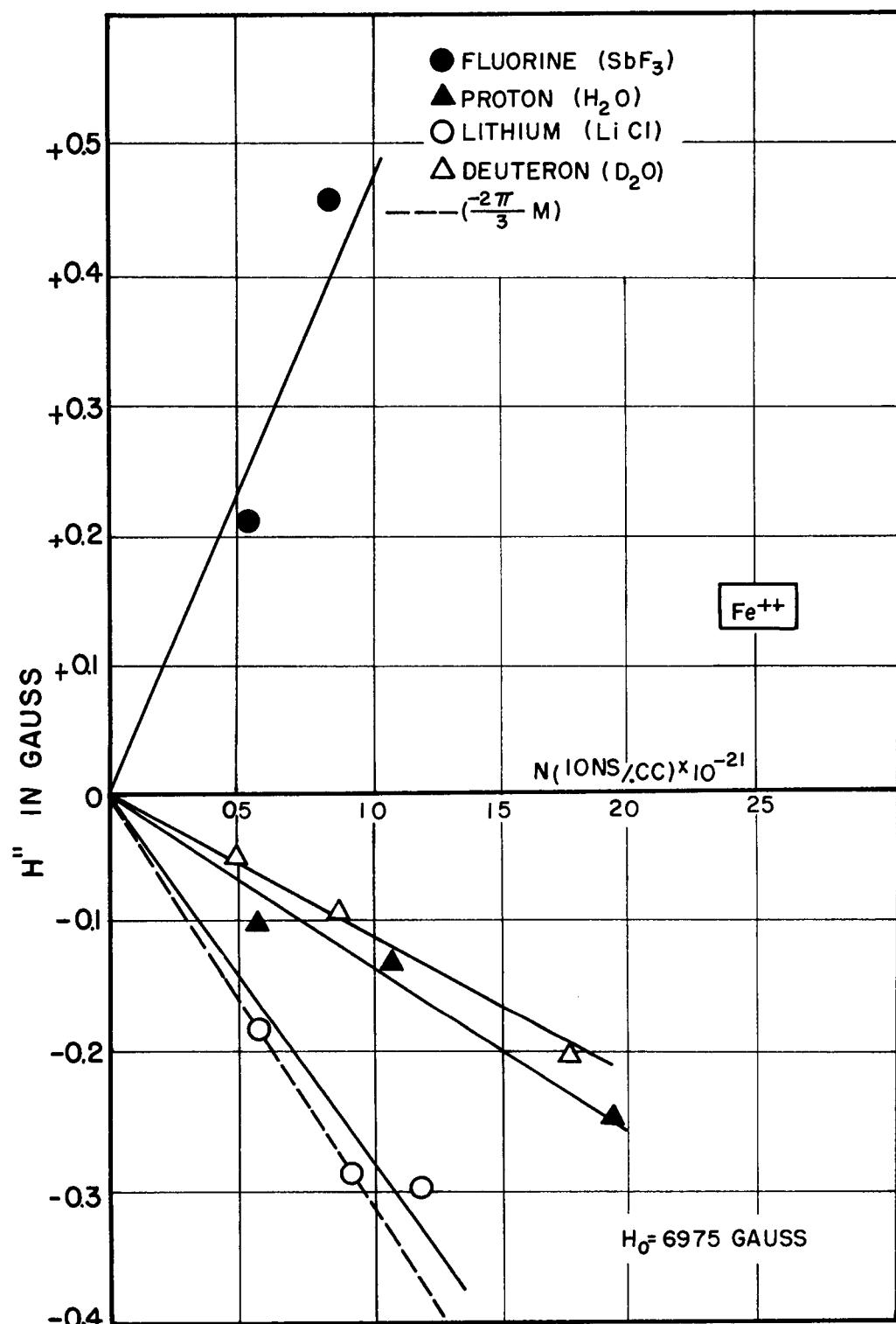


FIGURE 3.1 ILLUSTRATION OF THE DEPENDENCE
OF H'' ON RESONATING NUCLEUS. $FeCl_2$
"INFINITE" CYLINDER

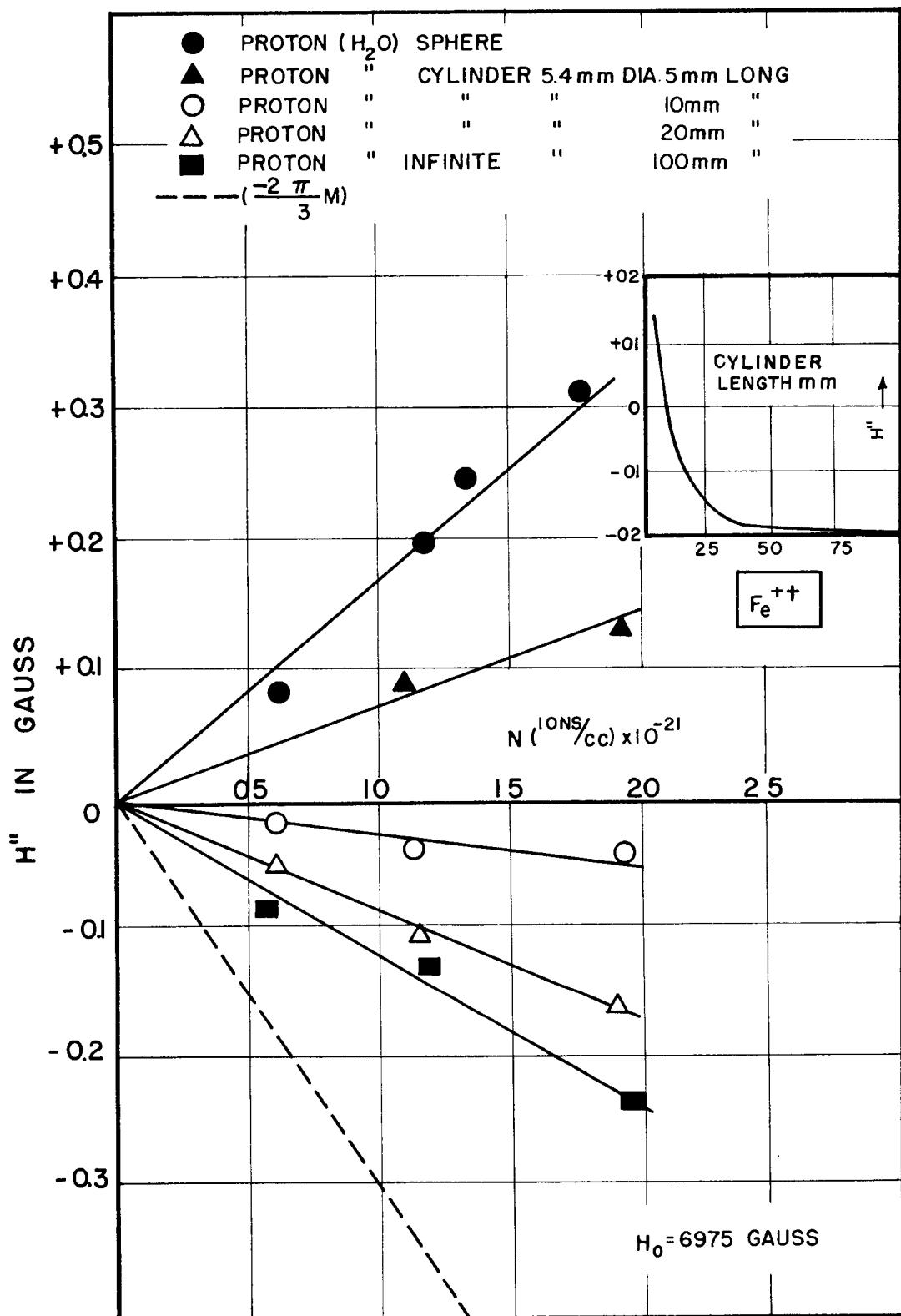


FIGURE 3.2 ILLUSTRATION OF THE DEPENDENCE
OF H'' ON SAMPLE SHAPE. $FeCl_2$ ADDED TO
 H_2O PROTON RESONANCE.

TABLE 3.4
MAGNETIC SHIELDING OF THE PROTON*

Z	Compound	ΔH	Statistical Error	$\sigma = \Delta H/H$
1	H ₂	0.169	± .002	$2.66 \pm .03 \times 10^{-5}$
5	B ₂ H ₆	0.220	.001	3.46
6	CH ₄	0.193	.002	3.03
7	NH ₃	0.199	.001	3.13
8	H ₂ O	0.172	.001	2.70
9	HF	0.147	.002	2.31
14	SiH ₄	0.183	.002	2.88
16	H ₂ S	0.195	.001	3.06
17	HC ₁	0.198	.001	3.11
33	AsH ₃	0.191	.001	3.00
34	H ₂ Se	0.215	.001	3.38
35	HB _r	0.219	.001	3.44
53	HI	0.269	.001	4.23

*Data are reduced to the unshielded proton as the zero reference. H is the applied field for the compound proton resonance less the field required for the unshielded proton resonance.

The statistical error refers only to the internal consistency of the measurements for the given compound. In addition there are systematic errors to a possible maximum of ± 1 per cent of observed differences in shielding as discussed in GW 51.

Gutowsky and Hoffman, J. Chem. Phys. 19, 1259 (1951)

the shielding shift vs temperature for the OH group. An additional experiment where ethyl alcohol was diluted 1 to 1 with chloroform gave an experimental shift in the OH group resonance comparable with a 350° K temperature of pure alcohol, in agreement with the predictions of Liddel and Ramsey.

Deuterium - ¹H²

G. Lindström (LM 51-2) gives reference to a personal communication from G. F. Newell indicating a small difference in the magnetic shielding

between D² and H¹ depending on changes in the amplitude of molecular vibration. A calculated value of $(1.1 \pm 0.2) \times 10^{-7}$ is determined by using the first term of Ramsey's expression. Newell also points out that this difference could be reduced by molecular vibrations affecting the second term of Ramsey's equation.

F. Bitter in a personal communication of February 10, 1953 reported the unpublished thesis of T. F. Wimett (MIT) concerning the chemical shifts in several hydrogen deuterium forms. The following chemical shifts were observed:

$$\frac{f_D}{f_H} (H_2 + D_2) - \frac{f_D}{f_H} (HD) = 0.000\ 000\ 010 \pm 0.000\ 000\ 009$$

$$\frac{f_D(HD) - f_D(D_2)}{f_D(HD)} = (0.48 \pm 0.37) \times 10^{-7}$$

A value obtained for the Ramsey-Purcell splitting in HD is:

$$\delta = 42.7 \pm 0.7$$

Lithium - ${}^3Li^{6,7}$

Dickinson (DN 51) observed no shifts in aqueous solutions of the following lithium compounds: LiCl, LiBr, LiC₂H₃O₂, LiNO₃, Li₂SO₄, Li₃C₆H₅O₇, LiCHO₂, and LiC₇H₅O₃.

Knight (KG 50) and Abell (AB 52) have observed the resonance shift for metallic lithium with respect to aqueous solutions and find the value for $\Delta H/H = 0.02$ per cent.

Gutowsky (GW 52-2) has found the shift in the metal relative to LiNO₃ to be $\Delta H/H = 0.0261 \pm 0.002$ per cent.

Beryllium - ${}^4Be^9$

Townes et al (TW 50) have determined the shift in metallic beryllium with respect to an undesignated compound and find the shift $\Delta H/H = <0.02$ per cent.

Boron - ${}^5B^{11}$

Dickinson (DN 51) reports shifts in the boron resonance as given in Table 3.5. He points out that Pauling indicates that BF₃ differs from BC₁₃

TABLE 3.5
SHIELDING EFFECTS IN BORON COMPOUNDS*

Compound	Change in field from 7100 gauss	$\Delta H/H \%$ field decrease
$BF_3 \cdot O(C_2H_5)_2$	0.00	0.00
$B(OCH_3)_3$	-0.13	0.0018
$B Br_3$	-0.31	0.0044
$B Cl_3$	-0.33	0.0046

*Dickinson, Phys. Rev. 81, 717 (1951)

and BBr in the greater ionic character of the B-F bond (63% for B-F, 22% for B-Cl). Figure 3.3 shows this shielding graphically.

Nitrogen - $^7N^{14}$

Proctor and Yu (PR 50) observed shifts in the resonance of N^{14} in various compounds and ion complexes. The shifts relative to the NO_3^- ion are given in Table 3.6. Calculations of equivalent field shift and per cent

TABLE 3.6
NITROGEN FREQUENCY SHIFTS RELATIVE TO THE RESONANCE FROM THE
 NO_3^- ION AT 10,500 GAUSS*

Compound Observed	Frequency shift (kc)	Equivalent field shift	$-\Delta H/H \%$
NH_4^+ from NH_4NO_3 ,	-1.0 ± 0.1 kc	3.2 ± 0.3 gauss	0.036
$NH_4C_2H_3O_2$,			
NH_4Cl			
NH_3 liquid containing .6m $Cr(NO_3)_3$,	-1.2 ± 0.1 kc	3.9 ± 0.3 gauss	0.030
NH_4OH			
$(NH_2)CO$	-1.0 ± 0.1 kc	3.2 ± 0.3 gauss	0.036
KCN	-0.2 ± 0.1 kc	0.65 ± 0.3 gauss	0.006

*Based on Proctor and Yu, Phys. Rev. 77, 716 (1950)

shielding have been added to the original table of PR 50. The shift of the resonance frequencies for different compounds and field intensities is given

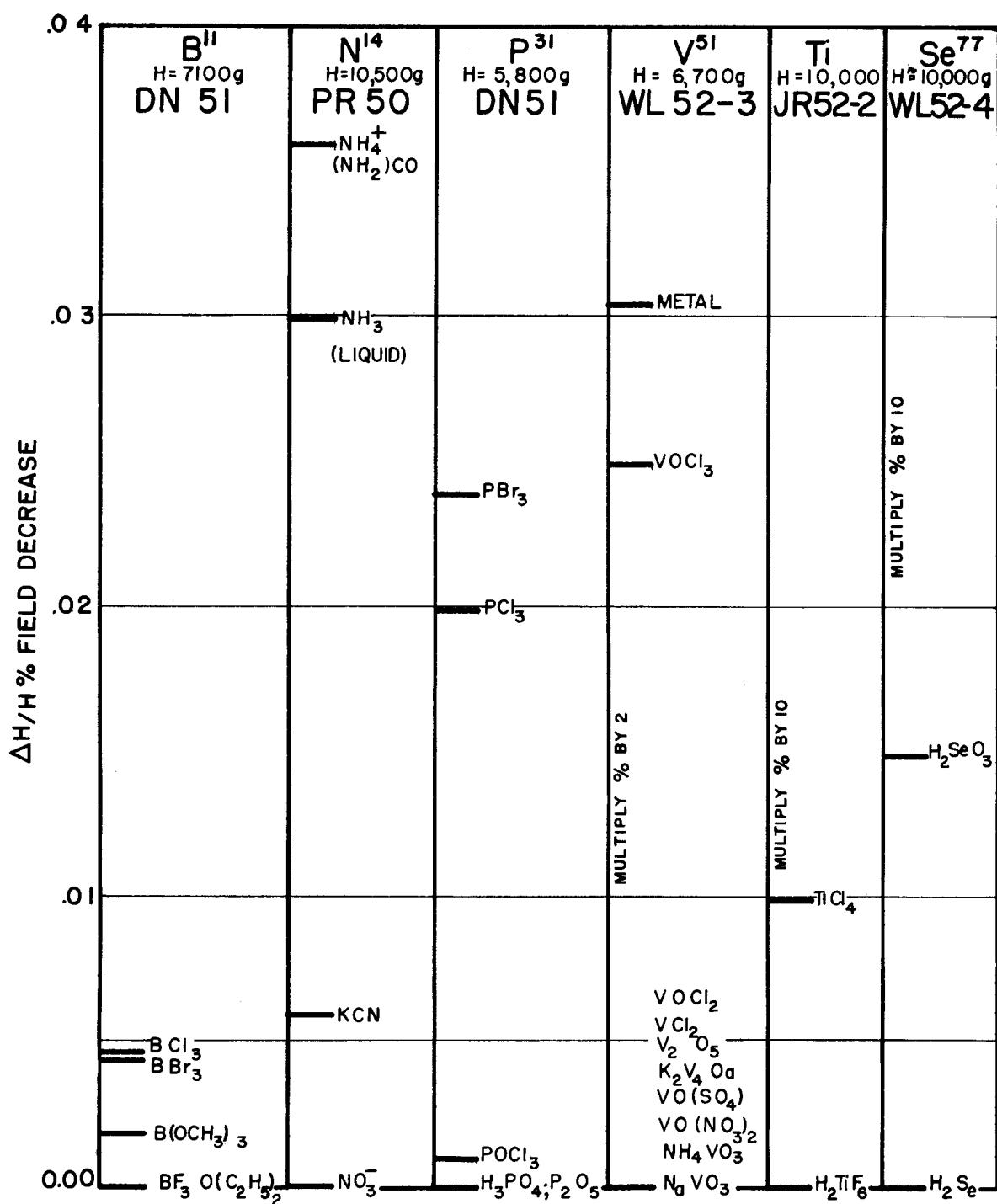


FIGURE 3.3 MAGNETIC SHIELDING OF VARIOUS COMPOUNDS

(CONTINUED ON FIG. 3.3 b.)

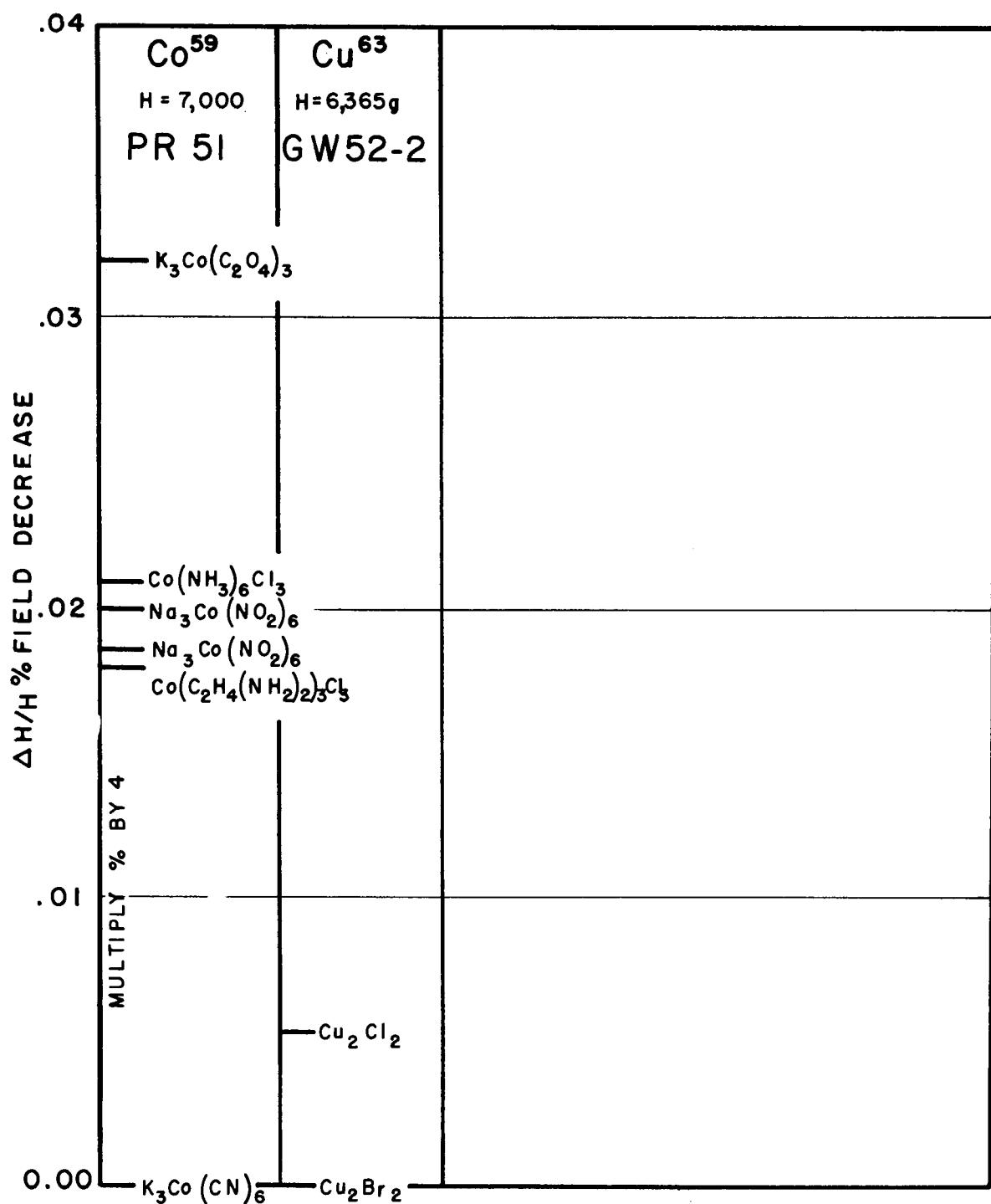


FIGURE 3.3 b MAGNETIC SHIELDING OF VARIOUS COMPOUNDS

in Table 3.7. In these, the resonance from NH_4 occurs for the highest value of applied field. The shifts corresponding to Table 3.6 are plotted in Figure 3.3.

TABLE 3.7

NITROGEN RESONANCE FREQUENCY DISPLACEMENTS WITH DIFFERENT COMPOUNDS AND FIELD INTENSITIES*

Compounds Observed	Displacement in kc at 10,500 gauss	Displacement in kc at 6700 gauss	Ratio (0.64)
NH_4^+ and NO_3^- from NH_4NO_3 in 2m. MnSO_4	1.6	0.9	0.5
HNO_3 and $\text{NH}_4\text{C}_2\text{H}_3\text{O}_2$	1.0	0.7	0.7
HNO_3 and $(\text{NH}_2)_2 \text{CO}$	1.0	0.6	0.6
NH_3 containing .6m $\text{Cr}(\text{NO}_3)_3$ and NO_3^- from NH_4NO_3	1.2	0.7	0.58

*Proctor and Yu, Phys. Rev. 77, 716 (1950)

It was also observed that the separation of the two nitrogen resonances of NH_4NO_3 was dependent upon the concentration of the MnCl_2 paramagnetic salt. The observed separations were:

<u>Sample</u>	<u>Separation</u>
7.5 molar NH_4NO_3 with no MnCl_2	1 kc or 3.2 gauss
NH_4NO_3 with 1 molar MnCl_2	1.4 kc or 4.5 gauss
NH_4NO_3 with 2 molar MnCl_2	1.6 kc or 5.2 gauss

No indication was given as to whether either resonance was fixed at a given field value and the other varied with concentration, or if both values shifted in the applied field with concentration change with one varying more than the other.

Fluorine - ${}_{9}\text{F}^{19}$

Dickinson (DN 50-2, DN 51) has observed shifts in several compounds of fluorine. The results reported in DN 51 correct the values of DN 50-2 which through an unfortunate error in field calibration gave values 36% too high. The corrected values are given in Table 3.8 and Figure 3.4.

TABLE 3.8
SHIELDING EFFECTS IN FLUORINE COMPOUNDS*

Compounds	Shift in gauss from 6975 gauss	$\Delta H/H \%$ field decrease
BeF_2	0.00	0.0000
$\text{BF}_3 \cdot \text{O}(\text{C}_2\text{H}_5)_2$	-0.10	0.0014
HF	-0.10	0.0014
KF (aqueous)	-0.40	0.0057
NaF (aqueous)	-0.42	0.0060
SbF_3	-0.63	0.0090
$\text{C}_2\text{F}_3\text{Cl}_3$	-0.67	0.0096

*Dickinson, Phys. Rev. 81, 717 (1951)

Gutowsky and Hoffman (GW 50) have reported shifts for several complex fluorides as well as for the simple fluorides. Agreement exists between these results and those of Dickinson except for the BF_3 etherate.

It is suggested that in the simple compounds, the magnetic shielding of the F^{19} nucleus chemically bonded to another element is related to the position of that element in the periodic table. For elements in a given period, the shielding decreases with increasing atomic number, while for elements in a single column, the shielding increases with increasing atomic number. (In this case the resonance appearing at the highest applied field is considered by the authors to have the greatest shielding.) In complex fluorides, the shielding also depends on inductive effects of neighboring chemical bonds. The measurements reported show no temperature dependence over a range of 225° . Multiple structure is observed in some resonances of the complex fluorides. Measurements are tabulated in Table 3.9 and compared with other observations in Figure 3.4.

G. Lindström (LM 51-2) has reported shifts in several fluorine compounds. These are listed in Table 3.10 and compared in Figure 3.4. The values given in the reference have been converted to per cent decrease in field relative to HF and relative to BeF_2 assuming HF to occur at a field value 0.0013 per cent lower than BeF_2 .

Attention is called to the measurements of the University of Illinois group (GW 52) on the electron distribution in molecules with particular reference to the fluorine shielding in substituted benzene derivatives.

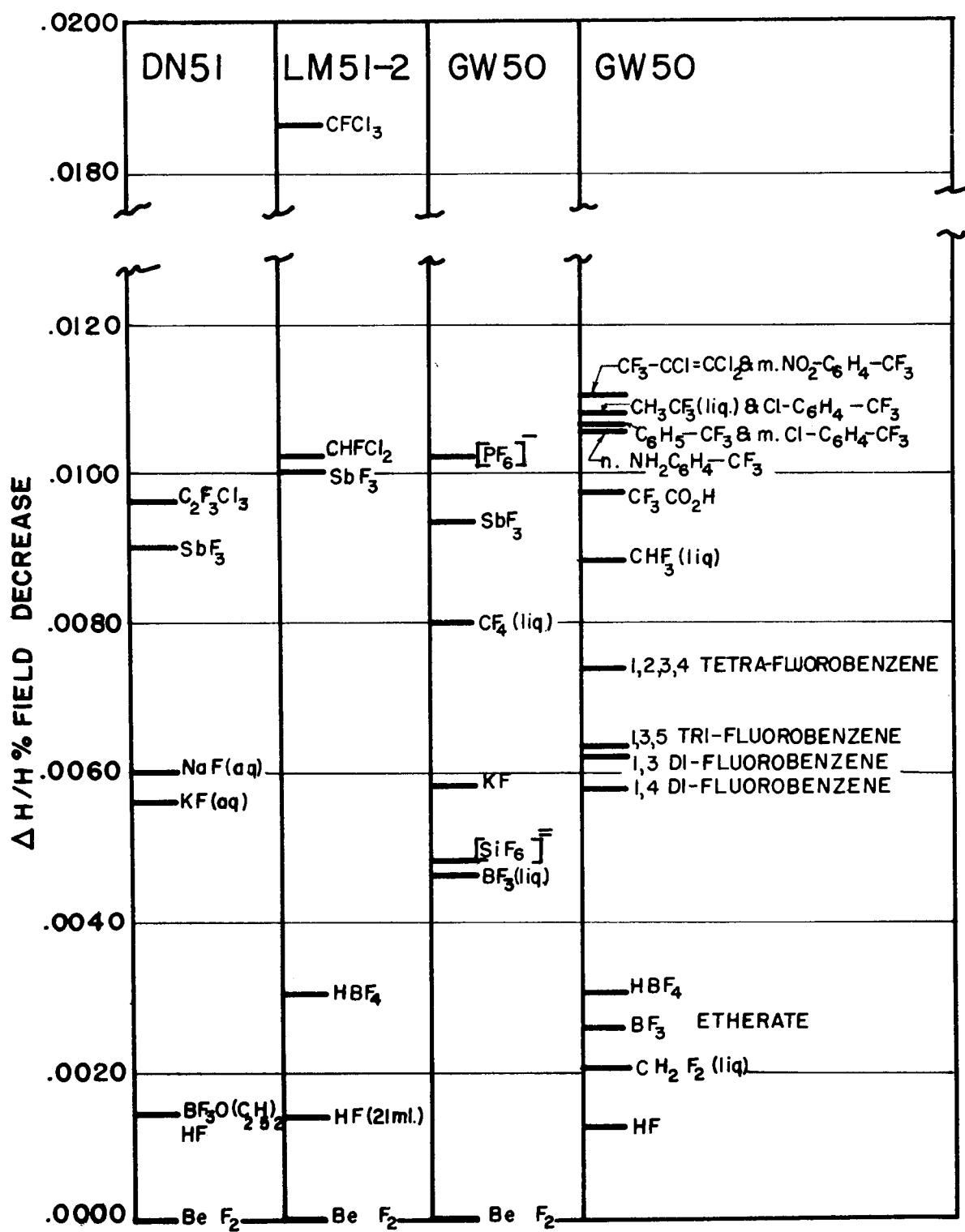


FIGURE 3.4 MAGNETIC SHIELDING IN FLUORINE COMPOUNDS

TABLE 3.9
MAGNETIC SHIELDING IN FLUORINE COMPOUNDS*

A. Simple Fluorides

Compound	$\Delta H/H \%$ field decrease
BeF_2	0.0000
BF_3 (liquid)	0.0046
$(\text{SiF}_6) =$	0.0048
F^- in sat aq KF	0.0058
CF_4 (liquid)	0.0080
SbF_3 sat aq	0.0093
$(\text{PF}_6)^-$ in aq NH_4PF_6	0.0102

B. Complex Fluorides

Compound	$\Delta H/H \%$ field decrease
HF conc aq	0.0013
CH_2F_2 (liquid)	0.0020
BF_3 etherate	0.0025
HBF_4	0.0030
1,4 - di-fluorobenzene	0.0057
1,3 - di-fluorobenzene	0.0062
1,3,5 - tri-fluorobenzene	0.0063
1,2,3,4 - tetra-fluorobenzene	0.0073
CHF_3 (liquid)	0.0088
$\text{CF}_3\text{CO}_2\text{H}$	0.0097
$n \text{ NH}_2\text{C}_6\text{H}_4 -\text{CF}_3$	0.0105
$\text{C}_6\text{H}_5-\text{CF}_3$ and $m \text{ C}_1-\text{C}_6\text{H}_4 -\text{CF}_3$	0.0106
CH_3CF_3 (liquid) and $\text{O}^3\text{Cl}-\text{C}_6\text{H}_4 -\text{CF}_3$	0.0107
$\text{CF}_3-\text{CCl}=\text{CCl}_2$ and $m \text{ NO}_2-\text{C}_6\text{H}_4 -\text{CF}_3$	0.0110

*Gutowsky and Hoffman, Phys. Rev. 80, 110 (1950)

TABLE 3.10
MAGNETIC SHIELDING IN FLUORINE COMPOUNDS*

Compound	$\Delta H/H\%$ decrease in field	$\Delta H/H\%$ relative decrease from BeF_2
BeF_2	—	0.0000
HF (21.5 molar)	0.0000	0.0013
HBF_4 in excess		
H_3BO_3	0.0016	0.0030
SbF_3 in HF	0.0087	0.0100
CHFCl_2 liquid	0.0088	0.0101
CFCl_3 liquid	0.0172	0.0185

*Values were calculated from frequency ratio data for column 2 and a value of BeF_2 to HF relative decrease of 0.0013% was taken from DN 51 and GW 50.

Based on data of Lindström, Arkiv fur Fysik 4, 1, (1951)

Sodium - ^{23}Na

Sheriff and Williams (SW 51) have reported an apparent shift in the sodium resonance in the compounds $\text{Na}_2\text{B}_2\text{O}_4$ and NaBr . The shift corresponds to a $\Delta H/H = 0.000101$ with NaBr occurring at the highest value of applied field.

Dickinson (DN 51) observed no measurable shifts in NaI , $\text{NaC}_7\text{H}_5\text{O}_3$, NaF , $\text{Na}_2\text{Cr}_2\text{O}_7$, Na_2CrO_4 , NaCHO_2 , and $\text{Na}_3\text{C}_6\text{H}_5\text{O}_7$ all in aqueous solution.

W. D. Knight (KG 50) determined the resonance in metallic sodium to be at a frequency 0.104 per cent lower than the resonance in NaCl (See Figure 3.5).

H. S. Gutowsky (GW 51-5) has measured the temperature effects on the resonance of sodium metal relative to that of sodium chloride and indicates a variation with change in temperature of the sample. A value of $\Delta H/H = 0.099$ per cent is indicated for 25°C . An equation for calculation of the shift as a function of temperature is presented to obtain agreement with experimental curves. A transition in the line width of the resonance occurs at low temperatures and it is suggested that this is due to a diffusion process. The sodium resonance shift starts at a point 65 degrees above the point where the line width transition occurs. A similar effect has been noted for lithium.

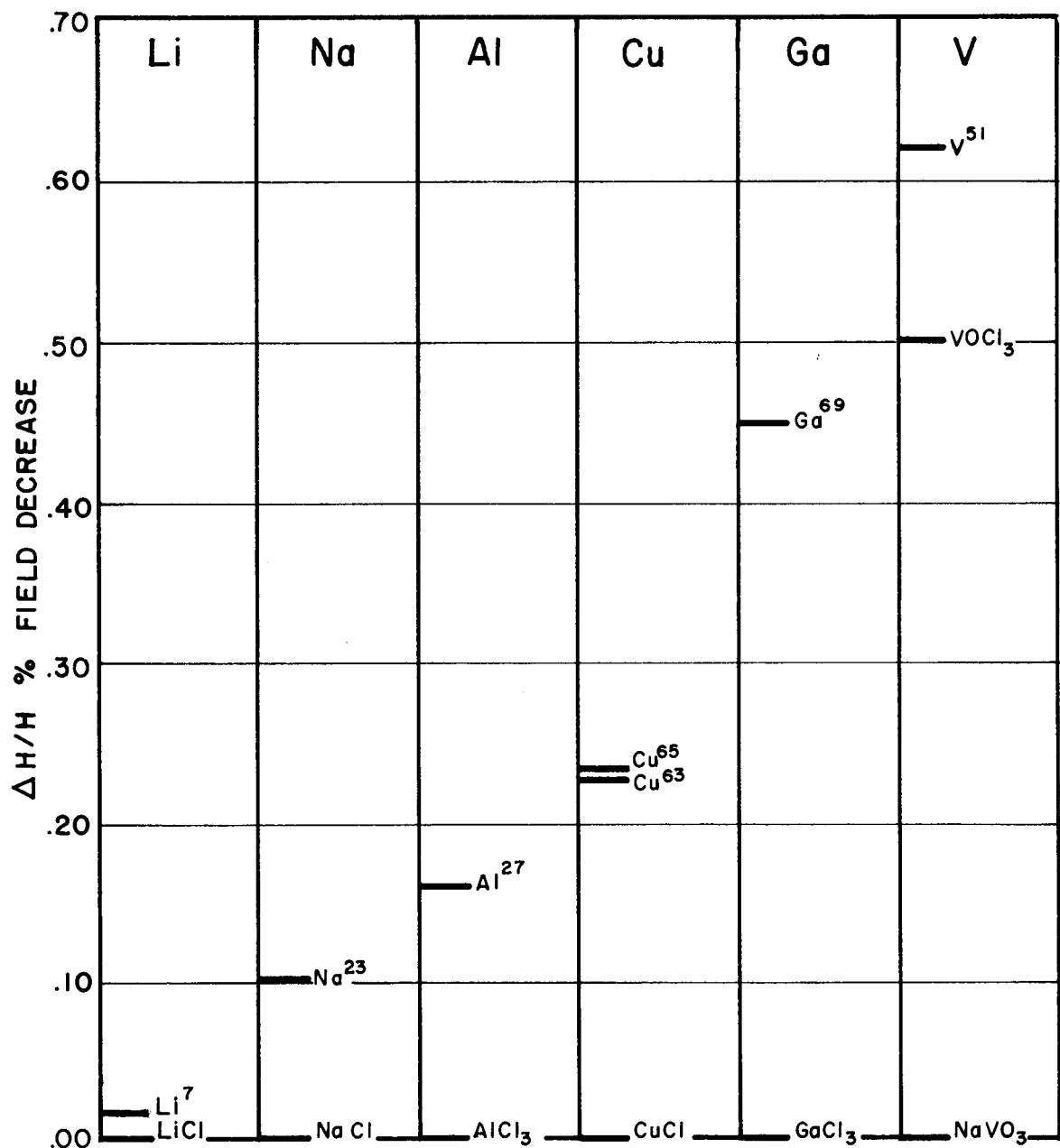


FIGURE 3.5 SHIELDING EFFECTS IN METALS

(CONTINUED ON FIG. 3.5 b.)

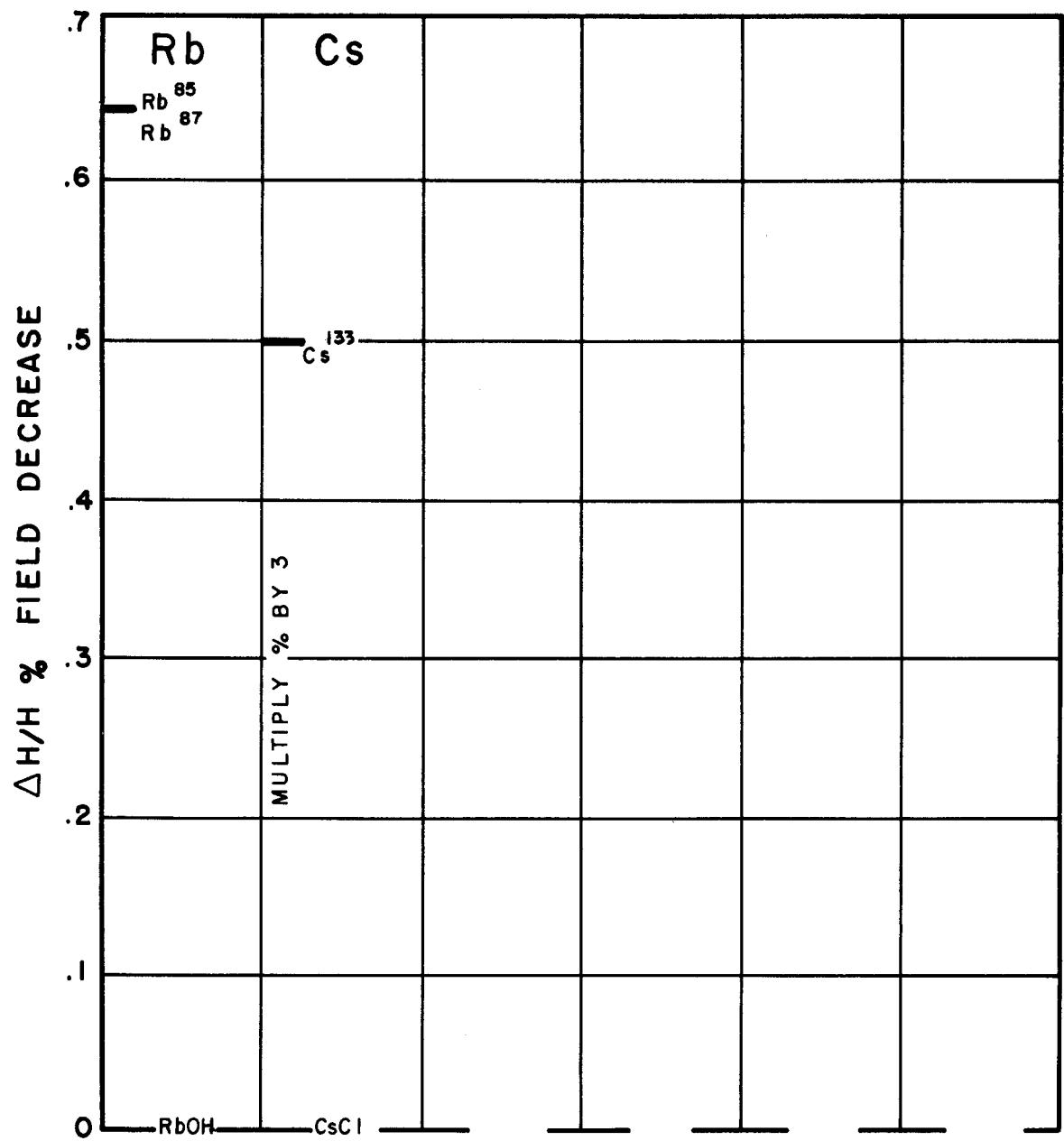


FIGURE 3.5 b. SHIELDING EFFECTS IN METALS

H. S. Gutowsky (GW 52-2) has measured the metal shift relative to aqueous NaOH and finds $\Delta H/H = 0.112 \pm 0.001$ per cent.

Aluminum - ^{27}Al

W. D. Knight (KG 50) has measured the shift in metallic aluminum and finds the resonance to occur at a frequency 0.159 per cent higher than for AlCl_3 (See Figures 3.5 and 3.5b).

H. S. Gutowsky (GW 51-5) has measured the shift in the resonance of aluminum in Al^{+3} aqueous solution relative to AlO_2^- solution and finds $H/H = 0.81 \times 10^{-4}$, and for anhydrous AlCl_3 relative to AlO_2^- solution the $\Delta H/H = 1.32 \times 10^{-4}$. In both cases the AlO_2^- solution occurred at the lower field value.

H. S. Gutowsky (GW 52-2) determined the shift in the metal resonance relative to aqueous AlCl_3 to be $\Delta H/H = 0.161 \pm 0.001$ per cent.

Phosphorus - ^{31}P

Dickinson (DN 51) observed shifts in the compounds of phosphorus as given in Table 3.11. A shift was observed characteristic of the 3 valent and 5 valent states. PCl_3 and PBr_3 involve 3p orbitals, while POCl_3 and H_3PO_4 involve 3p + 3s + one 3d. The shifts are plotted graphically in Figure 3.3.

TABLE 3.11
MAGNETIC SHIELDING IN PHOSPHORUS COMPOUNDS*

Compound	Shift in gauss at 5800 gauss	$\Delta H/H \%$ decrease
H_3PO_4 (aq)	0.00	0.0000
$\text{H}_4\text{P}_2\text{O}_7$ (aq)	0.00	0.0000
P_2O_5 (aq)	0.00	0.0000
POCl_3	0.05	0.0009
PCl_3	1.18	0.0200
PBr_3	1.30	0.0240

*Dickinson, Phys. Rev. 81, 717 (1950)

Titanium - $^{22}\text{Ti}^{47, 49}$

Jeffries (JR 52-2) has observed the resonances of Ti^{47} and Ti^{49} to be displaced by only 1 part in 5000, thereby explaining the complex waveform originally reported in JR 52. A shift between the compounds TiCl_4 (liquid) and H_2TiF_6 solution has been observed with the resonance signal from the latter appearing at 0.1 per cent higher field (See Figure 3.3).

Vanadium - $^{23}\text{V}^{51}$

Walchli and Morgan (WL 52-3) have reported shifts in various vanadium compounds as given in Table 3.12. No correlation with respect to valence can be made as in the case for the phosphorus compounds. Comparison is recorded graphically in Figure 3.3.

TABLE 3.12

MAGNETIC SHIELDING EFFECTS IN VANADIUM COMPOUNDS*

Compound	Valence	$\Delta H/H \%$ field decrease
NaVO_3	+ 5	0.00
Na_3VO_4	+ 5	0.00
NH_4VO_3	+ 5	0.00
$\text{VO}(\text{NO}_3)_3$	+ 4	0.00
$\text{VO}(\text{SO}_4)_2$	+ 4	0.00
$\text{K}_2\text{V}_4\text{O}_9$	+ 4	0.00
V_2O_5 powder	+ 5	0.00
VCl_2	+ 2	0.00
VOCl_2	+ 4	0.00
$\text{Pb}(\text{VO}_3)_2$	+ 5	line too broad
VOCl_3 (liquid)	+ 5	0.05
V metal powder	-	0.61

*No signals were observed in solid state V_2O_3 , or VF_3 . All compounds were aqueous solutions except for V_2O_5 and $\text{Pb}(\text{VO}_3)_2$ which were powders, and VOCl_3 a liquid.

Copper - $^{29}\text{Cu}^{63, 65}$

Shifts in metallic copper observed by Walchli (WL 52-5) indicate the resonance in powdered metallic copper to appear at a field 0.2 per cent lower than the resonance in Cu_2Cl_2 .

W. D. Knight (KG 50) has measured these shielding effects more precisely and has found the shielding between metallic copper and CuCl to be 0.229 per cent for Cu^{63} and 0.232 per cent for Cu^{65} (See Figure 3.5).

H. S. Gutowsky (GW 52-2) has measured the shift in metallic copper relative to solid Cu_2Br_2 and has found the $\Delta H/H = 0.237 \pm 0.001$ per cent for the Cu^{63} resonance and $\Delta H/H = 0.235 \pm 0.002$ per cent for Cu^{65} . In addition, Gutowsky (GW 51-5) has measured the shift between Cu_2Cl_2 and Cu_2Br_2 and finds $\Delta H/H = 0.0056 \pm 0.003$ per cent with Cu_2Br_2 occurring at the higher applied field.

Cobalt - $^{27}\text{Co}^{59}$

Proctor and Yu (PR 51) have measured the effects of chemical compounds on the resonance frequency of Co^{59} . Table 3.13 lists their measured frequency values and tabulates the equivalent $\Delta H/H$ per cent for each compound. (See Figure 3.3b).

TABLE 3.13
MAGNETIC SHIELDING OF COBALT COMPOUNDS

Compound	Relative frequency	$\Delta H/H$ % decrease
$\text{K}_3\text{Co}(\text{CN})_6$	1.0000	0.000
$\text{Co}(\text{C}_2\text{H}_4(\text{NH}_2)_2)_3\text{Cl}_3$	1.0073 ± 0.0001	0.725
* $\text{Na}_3\text{Co}(\text{NO}_2)_6$	1.0074 ± 0.0001	0.735
	1.0081 ± 0.0001	0.804
$\text{Co}(\text{NH}_3)_6\text{Cl}_3$	1.0083 ± 0.0001	0.823
$\text{K}_3\text{Co}(\text{C}_2\text{O}_4)_3$	1.0130 ± 0.0001	1.283

*This compound has two resonances of 0.72 gauss line width which may come from two isomeric forms of this compound. For the first, second, and fourth listed compound a temperature dependence of 0.015 per cent was found for a temperature change of 60°C above 20°C . The change was measured as an increase in frequency.

Gallium - $^{31}\text{Ga}^{69, 71}$

W. D. Knight (KG 50) has found the resonance in metallic gallium to occur at a frequency 0.449 per cent higher than that in GaCl_3 (See Figure 3.5).

H. S. Gutowsky (GW 52-2) found the metal shift relative to aqueous GaCl_3 to be $\Delta H/H = 0.449 \pm 0.004$ per cent.

Selenium - $^{34}\text{Se}^{77}$

Walchli (WL 52-4) has observed shifts in the selenium resonance in H_2Se and H_2SeO_3 . The resonance for Se^{77} in H_2Se appearing 0.15 per cent higher in applied field than that for H_2SeO_3 (See Figure 3.3).

Rubidium - $^{37}\text{Rb}^{85, 87}$

D. F. Abell (AB 52) and W. D. Knight have reported the shift in metallic rubidium to be 0.60 per cent (compound for comparison not given).

H. S. Gutowsky (GW 52-2) has measured the shift in metallic rubidium relative to RbOH (aqueous) and finds $\Delta H/H = 0.650 \pm 0.005$ per cent for Rb85 and $\Delta H/H = 0.653 \pm 0.002$ per cent for Rb87.

Cesium - $^{55}\text{Cs}^{133}$

D. F. Abell and W. D. Knight (AB 52) have found the shift in metallic Cs to be 1 per cent (compound for comparison not specified).

H. S. Gutowsky (GW 52-2) has measured the shift in metallic cesium relative to aqueous CsCl and finds $\Delta H/H = 1.49 \pm 0.01$ per cent.

Lead - $^{82}\text{Pb}^{207}$

C. H. Townes et al. (TW 50) have reported the shift for metallic lead to be 1.2 per cent (compound for comparison not specified).

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