A Table of Nuclear Moments, January 1950

J. E. MACK
University of Wisconsin, Madison, Wisconsin

I. GENERAL DESCRIPTION OF THE TABLE

THIS paper consists of a table of nuclear moments, accompanied by a discussion to enhance its usefulness. It is not a general review of the subject.

Definitive tables can be compiled only in dead subject fields. Currently there is so much activity in the study of nuclear moments that any printed table of them is bound to be obsolescent before it reaches its readers; but it is at just such a time that such a table can be especially useful. Previous lists and tables of this sort[1–14, a] show a steady growth in the number of nuclear species listed. Now we are in a transition period: Currently there is experimental evidence on the nuclear moments of all except 15 of the 109 stable isotopes with odd atomic mass integer. The emphasis has recently shifted toward increased accuracy in the determinations. Still, several of the spins already listed need redetermination, many stable even-even isotopes and an unlimited number of radioactive species remain to be studied, and the field of quadrupole and higher moments has hardly been scratched.

Table I is a compilation, prepared at the beginning of 1950, of the value of the mechanical or spin moment I, and the most probable values of the magnetic dipole moment μ and the electric quadrupole moment Q, for the normal state of each nuclear species. Here I is expressed as a multiple of the Planck-Dirac constant, $\hbar$, μ as a multiple of the nuclear magneton $e\hbar/2M_pc$, and Q as a multiple of the proton barn $e\times 10^{-24}$ cm^2, while e is the magnitude of the electronic charge in cgsesu, M_p is the proton rest mass, and c is the velocity of light in vacuum. Positive Q implies a prolate, and negative Q an oblate, aspherical distribution of charge, according to the defining equation $Q=\int \rho_I(3z^2-r^2)d\tau$, where ρ_I stands for the charge density for the state $m_I=I$, and the other symbols have their usual meanings.

The several columns in the main body of the table show, respectively:

1. N, the neutron number (bold face, odd neutron species)
2. Z, the proton number or atomic number (bold face, odd proton species)
3. the chemical symbol for the element
4. $A=N+Z$, the atomic mass integer (*, radioactive species)
5. I, (unit, $\hbar$)
6. μ, (unit, $e\hbar/2M_pc$)
7. Q, (unit, $e\times 10^{-24}$ cm^2)
8. the reference symbols to the literature for I
9. the reference symbols to the literature for μ (italicized, references used in calculations)
10. the reference symbols to the literature for Q (italicized, references used in calculations)
11. the chemical symbol for the element, again
12. A, the atomic mass integer, again.

Quantities that are considered somewhat doubtful are enclosed in parentheses (but where an enclosed quantity is in competition with one not so enclosed, the presumption is strongly in favor of the latter). A question mark

[1] L. Pauling and S. Goudsmit, *The Structure of Line Spectra* (McGraw-Hill Book Company, Inc., New York, 1930).
[2] K. Murakawa, Sci. Pap. Tokyo IPCR **17**, 6 (1931).
[3] H. Kallman and H. Schüler, Ergeb. d. exakt. Naturwiss **11**, 134 (1932).
[4] E. Marx, *Handbuch der Radiologie* (Akademische Verlagsgesellschaft, Leipzig, 1933).
[5] H. E. White, *Introduction to Atomic Spectra* (McGraw-Hill, Book Company, Inc., New York, 1934).
[6] =SH35$_2$ of Table I (quadrupole moments only).
[7] H. A. Bethe and R. F. Bacher, Rev. Mod. Phys. **8**, 82 (1936).
[8] G. Herzberg, *Atomic Spectra and Atomic Structure* (Prentice-Hall, Inc., New York, 1937).
[9] R. Gregoire, *Tables Annuelles de Constantes, etc., Physique Nucleaire* (Hermann and Cie, Paris, 1938), No. 26.
[10] =SH38 of Table I (quadrupole moments only).
[11] J. Mattauch and S. Flügge, *Nuclear Physics Tables, 1941* (Interscience Publishers, Inc., New York, 1946), English translation.
[12] W. F. Meggers, J. Opt. Soc. Am. **36**, 431 (1946).
[13] H. H. Goldsmith and D. Inglis, Brookhaven report BNL-1-5 (1948).
[14] H. L. Poss, Brookhaven report BNL 26 (T-10) (1949). Most of the difference in completeness between Poss' excellent table and this, indicated in reference a, arises from this table's inclusion of zero moments. I am particularly indebted to Dr. Poss for his generosity in making available to me material that he received too late for inclusion in his table. His table is in certain respects more detailed than this one and more useful to workers in the field of nuclear moment determination, although a little more cumbersome for the general user, for instead of publishing a single value for μ and a single value for Q for each species, he lists all the values given by the several authors (except for obsolete spin values). I have made full use of it in the revision of the preliminary edition of this table mentioned at the end of this paper. Had I realized, before the publication of this table was scheduled, that Poss' (mailed December 13) was imminent, I probably would not have undertaken the publication of this.
[a] The development in quantity and in quality of our knowledge of nuclear moments may be gauged qualitatively from the accompanying tabulation of some previous extensive lists or tables of nuclear moments.

TABLE (a). The growth of nuclear moment tables.

Reference	Year	Species with data	Odd species	Greatest number digits	Quadrupole moments	Disagreements in I with this table (approximate)
1.	1930	13	12	—	0	1
2.	1931	40	23	—	0	6
3.	1932	52	34	—	0	7
4.	1933	55	36	—	0	6
5.	1934	74	51	2	0	7
6.	1935	—	—	—	8	
7.	1936	71	64	2	3	8
8.	1937	121	72	—	—	8
9.	1938	102	70	3	—	5
10.	1938	—	—	—	16	
11.	1941–6	81	72	4	20	4
12.	1946	89	78	5	21	5
13.	1948	107	87	5	28	5
14.	1949	112	98	7	39	3
This	1950	180	101	7	54	—

TABLE I. Nuclear moments, January 1950.

N	Z	Atom	A	I(ħ)	μ(n.m.)	Q(e×10⁻²⁴ cm²)	References I	References μ	References Q	Atom	A
1	0	*n*	1*	1/2	−1.912 80 ±9		SI37	AC40, *AQ47*, *BL48*, *RV49*		*n*	1*
0	1	H	1	1/2	+2.792 55 Sec. IIIA		DM27, HM30	KE39$_2$, ML41, TH49, TA49, *RV49*, GD49, *HP49*		H	1
1	1	H	2	1	+0.857 354 ±9	+0.002 73 ±5	FA34, MY34	KE39$_2$, AQ47, *RU47*, *BL47$_3$*, *BI47*, *WJ49*, *SN49*, *ZI49*, *SR50*	*KE39$_1$*	H	2
2	1	H	3*	1/2	+2.978 643 ±28		BL47$_1$, DQ49	*AN47*, *BL47$_2$*		H	3*
1	2	He	3	1/2	(−)2.127 414 ±3		DS49	*AN48*		He	3
2	2	He	4	0			MU29			He	4
3	3	Li	6	1	+0.821 89 ±4h }r	|<9·10⁻⁴|	MB37	KU49$_2$, *KU49$_4$*	KU49$_1$	Li	6
4	3	Li	7	3/2	+3.255 86 ±11	+(0.02) ±2	HE30, GS30, GU31	GS32, FP35, ML41, *BI49*, KU49$_2$, *SN49*, *ZI49*	*KU49$_3$*	Li	7
5	4	Be	9	Foot- note b	(−)0.784 9×*I* ±5			KU39$_1$, *DN49$_1$*, *CH49*		Be	9
5	5	B	10	3	+1.800 4 ±7	+0.06 ±4	GO48$_2$	ML39$_1$, *BI49*	*GO48$_2$*	B	10
6	5	B	11	3/2	+2.688 58 ±28	+0.03 ±2	GO48$_2$	ML39$_1$, BI49, *AD49*, *ZI49*, AE49	*GO48$_2$*	B	11
6	6	C	12	0			MU29, HM30			C	12
7	6	C	13	1/2	+0.702 25 ±14		TW39, HH41, JE47, TW47$_2$	HH41, *PH49*		C	13
8	6	C	14	*0			JE48, RU48			C	14*
7	7	N	14	1	+0.403 65 ±3	+0.02	KR28, OR28, RR29, TW47$_1$	KU39$_2$, *PR50*	DE46, TW47$_1$, TW48	N	14
8	7	N	15	1/2	−0.282 99 ±3		KS38, WO38	ZA40, *PR50*		N	15
8	8	O	16	0			MU29			O	16
9	8	O	17	(1/2)		|<0.02|			LO49	O	17
10	8	O	18	(0)		|<4·10⁻³|			TW48	O	18
10	9	F	19	1/2	+2.628 5 ±7		GA29, GO48$_1$	CA33, ML41, *PH49*, *SN49*, *ZI49*		F	19
10	10	Ne	20	(0)	~0			HC27		Ne	20
11	10	Ne	21	3/2 (>3/2?)	<0		KH49	KH49		Ne	21
12	10	Ne	22	(0)	~0			HC27		Ne	22
11	11	Na	22*	3	+1.745 82 ±22h		DI48$_1$	*DI49$_2$*		Na	22*
12	11	Na	23	3/2	+2.217 11 ±25		JF33, GS33, RA34	EL34, FP35, ML41, *BI49*, KU49$_2$, ZI49		Na	23
12	12	Mg	24	(0)	~0			MW31		Mg	24
13	12	Mg	25	5/2(±) Footnote b	−0.96(±) ±7h		CR49$_3$, CR50	*CR49$_3$*		Mg	25
14	12	Mg	26	(0)	~0			AR50			
14	13	Al	27	5/2	+3.640 8 ±4	+0.156 ±3	HN38$_2$, LE49	ML39$_2$, *BI49*, *ZI49*	LE48, DI49$_3$, *LE49*	Al	27
14	14	Si	28	(0)		~0			TW49$_2$	Si	28
15	14	Si	29	(1/2)		~0			TW49$_2$	Si	29
16	14	Si	30	(0)		~0			TW49$_2$	Si	30
16	15	P	31	1/2	+1.131 65 ±20		JE32	*PO48$_2$*, *BI49*, *CH49*, CR49$_5$		P	31
16	16	S	32	0			ND31, OL36			S	32
17	16	S	33	3/2	(+)(0.3±0.2, 0.9)	−0.08	TW48	JD50, RU50, XX50	TW48	S	33
18	16	S	34	(0)		|<2·10⁻³| }r			TW47$_2$, TW48	S	34
19	16	S	35*	3/2		+0.06	CO49		*c*TW48, CO49	S	35*
20	16	S	36	(0)		<0.01			LO49	S	36
18	17	Cl	35	3/2	+0.821 91 ±22	−0.079 5 ±5	TW47$_1$	*BI49*, DI49$_3$, *CH49*	TW48, GO48$_1$, DI48$_2$, *DI49$_3$*	Cl	35
19	17	Cl	36*	2		−0.017 2 ±4	TW49$_1$		TW49$_1$	Cl	36*
20	17	Cl	37	3/2	+0.684 14 ±24	−0.062 1 ±5	TW47$_1$	KU39$_3$, DI49$_3$, *PR50*	TW48, GO48$_1$, DI48$_2$, *DI49$_3$*	Cl	37
18	18	A		(0)	~0			KP37$_2$		A	36
22	18	A		(0)	~0			KP37$_2$		A	40
20	19	K	39	3/2	+0.391 ±1h		ML35, KU39$_2$	ML35, FP35, KU39$_2$, KU40, *cTA49*		K	39
21	19	K	40*	4	−1.291 ±4h }r		ZA42	ZA42, *c*TA49, DI49$_2$		K	40*
22	19	K	41	3/2	+0.215 ±1h		ML35, MB36	ML35, MB36, KU49$_2$, *c*TA49		K	41
20	20	Ca	40	(0)	~0			FR31		Ca	40
23	20	Ca	43							Ca	43
24	21	Sc	45	7/2	+4.8		KP34$_3$, SH34$_4$	KP37$_1$		Sc	45
25	22	Ti	47							Ti	47
27	22	Ti	49							Ti	49
28	23	V	51	7/2	(+)5.147 8 ±5		KP34$_2$, PR50	*KG49$_2$*, PR50		V	51
29	24	Cr	53							Cr	53
30	25	Mn	55	5/2	+3.468 1 ±4		WH30	WH30, FI38, *PR50*, *CH50*		Mn	55
31	26	Fe	57		~0			*GV49$_2$*, *BS49*, *RW50*		Fe	57
32	27	Co	59	7/2	+4.648 4 ±6		GR33$_1$, KP34$_1$, MO34, RS36	MO34, *PR50*		Co	59
33	28	Ni	61		~0			AR50		Ni	61
34	29	Cu	63	3/2	+2.226 17 ±36	−0.26 ±10	RT32	GQ33, SH36$_2$, SH37$_2$, *PO48$_1$*, *BI49*, ZI49	SH35$_2$, SH36$_2$, *BQ49$_2$*	Cu	63
36	29	Cu	65	3/2	+2.384 5 ±4	−0.15 ±10	RT32	GQ33, SH36$_2$, SH37$_2$, *PO48$_1$*, *BI49*, *ZI49*	SH35$_2$, SH36$_2$, *BQ49$_2$*	Cu	65
34	30	Zn	64	(0)	~0			MW31		Zn	64
36	30	Zn	66	(0)	~0			MW31		Zn	66
37	30	Zn	67	5/2	+0.9		LY37, AR48	*LY37*		Zn	67
38	30	Zn	68	(0)	~0			MW31		Zn	68

within parentheses expresses stronger doubt as to the conclusiveness of the evidence.

Space is provided in the table for the stable odd-mass species for which there are no data.

In the list of bibliographical references following the main body of the paper, the information for each reference is given in four columns: first, an arbitrary symbol indicating the author and the year; second, the reference; third, the chemical symbols for the elements to which the reference pertains; and fourth, a symbol indicating the nature of the experimental evidence according to the following convention, adapted from previously published tables:[3, 13, 14]

- *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

II. THE MECHANICAL MOMENT, *I*

Unlike the moments μ and Q, the mechanical moment has no small uncertainties, i.e., it is a direct consequence of the commutation relations of quantum mechanics that I is exactly an integer for even A and exactly an odd half-integer for odd A. That the I-values listed without qualifying marks are fairly reliable, may be judged from the fact that in no case (except where the later tables have been based on new information) is there disagreement in any of the postwar tables on any of the mechanical moments listed here without qualifying marks;[b,15] at least in the case of this table the judgment was independent of all the other tables. Of course, we cannot exclude the possibility that a conclusion we have all trusted will turn out to be erroneous.

An extensive, but not altogether thorough, search has been made for data on the even-even isotopes; i.e., there may be information in existence further than is shown here, tending to confirm the generally-held supposition that the moments of all stable even-even isotopes are zero. There is no serious evidence against this supposition (if we neglect an undocumented indication[9] that $I=1$ for ${}^{16}{}_{14}\mathrm{Si}^{30}$).

III. THE MAGNETIC DIPOLE MOMENT, μ

III A. The Proton Moment

Just before the submission of the table there became available an important new datum: the first direct measurement of the magnetic moment of the proton in nuclear magnetons, n.m. (i.e., proton magnetons), by Hipple, Sommer, and Thomas (HP49). The ratio of the proton nuclear resonance frequency ν_p and the cyclotron frequency ν_c of the proton, measured in the same magnetic field, is directly the (diamagnetically uncorrected, see Section III C 1) value of $\mu({}^{0}{}_{1}\mathrm{H}^{1})$ in the specified unit, without dependence upon any other measurement whatsoever. Although the authors warn that the ratio, which I calculate from its given reciprocal as

$$\mu({}^{0}{}_{1}\mathrm{H}^{1},\ \text{uncorrected})=2.792\,469\pm 0.000\,078\ \text{n.m.},$$

is only a preliminary one pending the completion of their search for systematic errors, still the simple directness of the method is such that I prefer to use it (after diamagnetic correction) rather than to give weight to any of the other, less direct determinations; incidentally, any of the others would have yielded higher values. The application of the diamagnetic correction factor $[1-(3\pm2)\times10^{-5}]$ increases the raw value by $(8\pm6)\times10^{-5}$ magnetons, so after rounding the last digit, the best value available at this time, used in the table, becomes

$$\mu({}^{0}{}_{1}\mathrm{H}^{1},\ \text{diamagnetically corrected}) =+2.792\,55\pm 0.000\,10\ \text{n.m.}$$

As a reference value where ratios are accurately known, this number is supplemented by arbitrary zeros, e.g., 2.792 550 0.

All the other μ-values in the table are derived eventually from their ratios to $\mu({}^{0}{}_{1}\mathrm{H}^{1}$, uncorrected), and if the value accepted for $\mu({}^{0}{}_{1}\mathrm{H}^{1})$ changes, all the other quantities in column 6 ought to be changed in proportion.

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[b] All cases where there is any discrepancy in I-values not based upon new data, among the postwar tables, are listed here.

TABLE (b). Discrepancies in I among postwar tables.

Reference	${}^{5}{}_{4}\mathrm{Be}^{9}$	${}^{13}{}_{12}\mathrm{Mg}^{25}$	${}^{43}{}_{34}\mathrm{Se}^{77}$	${}^{143}{}_{,2}\mathrm{U}^{235}$
12	3/2	—	—	—
13	3/2	—	1/2	5/2 (7/2)
14	(3/2)	5/2	1/2, >1/2	5/2 or 7/2
This table	—	5/2 (±)	7/2±1, (1/2)	5/2, 7/2)

${}^{5}{}_{4}\mathrm{Be}^{9}$: The theoretically predicted[15] and usually accepted value of 3/2 for $I(\mathrm{Be}^{9})$ has little experimental basis. The exclusion of 1/2 has been suggested on plausibility arguments (KU39$_1$), and the exclusion of values greater than 3/2, on the opinion that with the known gyromagnetic ratio such a spin would have led to the partial resolution of the hyperfine structure (PD41). Alleged information that the spin is 3/2 is attributed by Allen, Burcham, and Wilkinson, Proc. Roy. Soc. **A192**, 114 (1937) to an authority who disclaims (KP50) any knowledge of the matter beyond the contents of reference PB41.

${}^{13}{}_{12}\mathrm{Mg}^{25}$: Crawford estimates (CR50) the probability of $I(\mathrm{Mg}^{25})$ being different from 5/2 at 1:10.

${}^{43}{}_{34}\mathrm{Se}^{77}$: Both $I=7/2\pm1$, from the application of the interval rule to a partly resolved hyperfine structure pattern (MA49$_1$), and $|Q|<2\cdot10^{-3}$ (GO50, TW50) seem to be rather well established for Se^{77}. They are not absolutely exclusive mutually, although the extraordinarily low Q-value, less than that of the deuteron, has naturally led to the surmise that I might be 1/2. An experiment has been undertaken (SA50) to determine the spin independently.

[15] M. Rose and H. A. Bethe, Phys. Rev. **61**, 205; Erratum, p. 993 (1937).

TABLE I.—*Continued.*

							References				
N	Z	Atom	A	$I(\hbar)$	μ(n.m.)	$Q(e\times10^{-24}\ \mathrm{cm}^2)$	I	μ	Q	Atom	A
38	**31**	Ga	69	3/2	+2.016 7 ±11 } r	+0.231 8 ±23 } r	JA32$_1$, CA32	GQ33, SH36$_4$, BG48, *PO48*$_2$	SH36$_4$, BG48, *DI49*$_3$	Ga	69
40	**31**	Ga	71	3/2	+2.561 4 ±10 } r	+0.146 1 ±15 } r	JA32$_1$, CA32	GQ33, SH36$_4$, BG48, *PO48*$_2$	SH36$_4$, BG48, *DI49*$_3$	Ga	71
38	32	Ge	70	(0)		$\lvert<7\cdot10^{-3}\rvert$			TW49$_2$	Ge	70
40	32	Ge	72	(0)		$\lvert<7\cdot10^{-3}\rvert$			TW49$_2$	Ge	72
41	32	Ge	73	9/2, >9/2		−0.21 ±10	TW49$_2$		*TW49*$_2$	Ge	73
42	32	Ge	74	(0)		$\lvert<7\cdot10^{-3}\rvert$			TW49$_2$,	Ge	74
44	32	Ge	76	(0)		$\lvert<7\cdot10^{-3}\rvert$			TW49$_2$	Ge	76
42	**33**	As	75	3/2	+1.4	+0.3 ±2	TL32$_2$, RO33, CR33, DE48	GQ33, SH35$_2$, *SH36*$_3$, *MW50*	SH35$_2$, *SH36*$_3$, DE48	As	75
40	34	Se	74	(0)			ST49			Se	74
42	34	Se	76	(0)	~0	$\lvert<2\cdot10^{-3}\rvert$	ST49	RF33	ST49, TW49	Se	76
43	34	Se	77	7/2±1, (1/2) Footnote b		$\lvert<2\cdot10^{-3}\rvert$	ST49, *MA49*$_1$		ST49, GO50, TW50	Se	77
44	34	Se	78	(0)	~0	$\lvert<2\cdot10^{-3}\rvert$	ST49	RF33	ST49, TW50	Se	78
46	34	Se	80	0		$\lvert<2\cdot10^{-3}\rvert$	OL34, ST49		ST49, TW50	Se	80
48	34	Se	82	(0)	~0			RF33		Se	82
44	**35**	Br	79	3/2	+2.105 76 ±37 } r	+0.26 ±8 } r	BU30, TL32$_1$, TW47$_1$	CA33, BR47, *PO47*, *ZI49*	TL40, GO47, GO48$_1$, TW48, PO47	Br	79
46	**35**	Br	81	3/2	+2.269 6 ±5 } r	+0.21 ±7 } r	BU30, TL32$_1$, TW47$_1$	CA33, BR47, *PO47*, *BI49*, *ZI49*	TL40, GO47, GO48$_1$, TW48, PO47	Br	81
46	36	Kr	82	(0)	~0			KP33$_2$		Kr	82
47	36	Kr	83	9/2	−0.970 4	+0.15	MW32, KQ38, KH49	KP33$_2$, SH38, *KE46*	KQ38, *SH38*	Kr	83
48	36	Kr	84	(0)	~0			KP33$_2$		Kr	84
50	36	Kr	86	(0)	~0			KP33$_2$		Kr	86
48	**37**	Rb	85	5/2	+1.353 2 ±4		KP33$_1$, ML36	KP33$_1$, KU39$_3$, *BI49*, KU49$_2$, *CH49*		Rb	85
50	**37**	Rb	87	3/2	+2.750 1 ±5		KP33$_1$, ML36	KP33$_1$, KU39$_3$, *BI49*, *ZI49*		Rb	87
48	38	Sr	86	(0)	~0			FR31		Sr	86
49	38	Sr	87	9/2	−1.1		HN38$_1$	*HN38*$_1$		Sr	87
50	38	Sr	88	(0)	~0			FR31		Sr	88
50	**39**	Y	89	1/2	−0.14		WK40, CR49$_4$	WK40, *CR49*$_4$		Y	89
51	40	Zr	91	5/2			AR49$_1$			Zr	91
52	**41**	Nb	93	9/2	+6.165 9	~0	BF34	*MF47*, *CH50*	MF47	Nb	93
50	42	Mo	92	(0)	~0			AR50		Mo	92
52	42	Mo	94	(0)	~0			AR50		Mo	94
53	42	Mo	95	(5/2)				AR50		Mo	95
54	42	Mo	96	(0)	~0			AR50		Mo	96
55	42	Mo	97	(5/2)				AR50		Mo	97
56	42	Mo	98	(0)	~0			AR50		Mo	98
58	42	Mo	100	(0)	~0			AR50		Mo	100
55	44	Ru	99							Ru	99
57	44	Ru	101							Ru	101
58	**45**	Rh	103	(1/2?)	>0		SM37	SM37		Rh	103
59	46	Pd	105							Pd	105
60	**47**	Ag	107	1/2	−0.086		JA37	JA37, *CR49*$_1$		Ag	107
62	**47**	Ag	109	1/2	−0.160		JA37	JA37, *CR49*$_1$		Ag	109
62	48	Cd	110	(0)	~0			SH29		Cd	110
63	48	Cd	111	1/2	−0.594 92 ±8		SH29	GQ33, JO33$_1$, PR49$_3$, PR50		Cd	111
64	48	Cd	112	(0)	~0			SH29		Cd	112
65	48	Cd	113	1/2	−0.622 38 ±8		SH29	GQ33, JO33$_1$, PR49$_3$, *PR50*		Cd	113
66	48	Cd	114	(0)	~0			SH29		Cd	114
68	48	Cd	116	(0)	~0			SH29		Cd	116
64	**49**	In	113	9/2	+5.486 ±3h } r	1.144	JA32$_2$, BA37, HD42	HD42, *cTA49*	*MD50*	In	113
66	**49**	In	115	9/2	+5.500 ±3h } r	1.161	CA32, JA32$_2$, PC34	SH37$_1$, ML38, KU48, *cTA49*, MD50	SH35$_2$, BA37, HA39, DI49$_3$, *MD50*	In	115
65	50	Sn	115	1/2	−0.917 79 ±10		GV49$_1$	GV49$_1$, PR49$_3$, *PR50*		Sn	115
66	50	Sn	116	(0)	~0			MW31		Sn	116
67	50	Sn	117	1/2	−0.999 82 ±10 } r		SH33, TL33	TL33, TL41, PR49$_2$, *PR50*		Sn	117
68	50	Sn	118	(0)	~0			MW31		Sn	118
69	50	Sn	119	1/2	−1.046 00 ±10 } r		SH33, TL33	TL33, TL41, PR49$_2$, *PR50*		Sn	119
70	50	Sn	120	(0)	~0			MW31		Sn	120
70	**51**	Sb	121	5/2	+3.7 } r	−0.3 ±2	BD32, CR34	GQ33, *CR34*	SH35$_2$, TM40, *MW49*	Sb	121
72	**51**	Sb	123	7/2	+2.8 } r	−1.2 ±2	BD32, CR34	GQ33, *CR34*	SH35$_2$, TM40, *MW49*	Sb	123
71	52	Te	123	1/2	} r		MA49$_2$	*MA49*$_2$		Te	123
73	52	Te	125	1/2	} r		FO49			Te	125
74	52	Te	126	(0)	~0			RF33		Te	126
76	52	Te	128	(0)	~0			RF33		Te	128
78	52	Te	130	(0)	~0			RF33		Te	130
74	**53**	I	127	5/2	+2.808 6 ±8	−0.59 ±20 } r	MW33, GO47	*PO48*$_2$, *ZI49*	SC39, MW39, GO47, GO48$_1$, TW48	I	127
76	**53**	I	129*	7/2	(+)2.74 ±14h	−0.43 ±15 } r	LI49	*GO48*$_1$	LN49	I	129*
75	54	Xe	129	1/2	−0.8 } r		KP33$_3$, JO33$_2$, RS50	*KP33*$_3$		Xe	129
77	54	Xe	131	3/2	+0.7 } r	$\lvert<0.1\rvert$	KP33$_3$, KQ38, RS50	*KP33*$_3$	KQ38, *SH38*	Xe	131
78	54	Xe	132	(0)	~0			JO33$_2$		Xe	132
80	54	Xe	134	(0)	~0			JO33$_2$		Xe	134
82	54	Xe	136	(0)	~0			JO33$_2$		Xe	136
78	**55**	Cs	133	7/2	+2.577 1 ±9	$\lvert\leqslant0.3\rvert$	KP32, JA33, CO34, FL37	CO34, KU39$_2$, *BI49*, DI49$_2$, *CH49*	SC40	Cs	133
80	**55**	Cs	135*	7/2	+2.727 1 ±33h		NA49	NA49, *DI49*$_2$		Cs	135*
82	**55**	Cs	137*	7/2	+2.839 7 ±30h		DI49$_1$, NA49	NA49, *DI49*$_2$		Cs	137*

III B. The Deuteron-Proton Moment Ratio

The most studied relationship between nuclear magnetic moments is the ratio between the moments of the deuteron and the proton. Because of the special interest of this ratio we shall consider the data in detail. While the richness and accuracy of the data available make it far from typical, the averaging procedure outlined below may be considered representative of the method of arriving at μ-values for the table.

For reasons discussed below (Section III C 2ff.) only the nuclear resonance experiments have been considered in the calculation of $\mu({}^1_1H^2)$. The data are shown in Table II. Since I have no information to guide me otherwise, the weights assigned are inversely as the uncertainties given by the respective authors. The mean value is 0.307 015 0; to this I assign an uncertainty (see Section III D) of 0.000 003, although that is higher than was assigned to most of the individual determinations, in order to have at least some overlap with the uncertainty ranges of all the determinations. Bitter (reference BI50) recommends an uncertainty assignment three times as great as mine. In view of certain physical questions involved (Section III C) it does not appear suitable to try to evaluate the uncertainty in any more detail. One of the determinations has an assigned uncertainty greater in order of magnitude than any of the others. If it had been neglected, the mean would have been different by only 0.000 000 1.

Determinations BI47 and WJ49 were made in the same laboratory, and so were SN49 and LM50. In the latter set of experiments extraordinary precautions were taken to attain a homogeneous field, and homogeneity to the order of 10^{-5} was actually attained. Whether the precautions justify giving each of the two LM50 values almost as much weight as all the others, from five laboratories, as has been done here in accepting all the $\pm$ ranges, is debatable; but the LM50 values lie so near the mean that even completely neglecting LM50 would have led to a result only 0.000 000 6 lower.

It would be premature to discard any of the values in Table II because the samples were in chemical combination; yet in view of the chemical effects, Sec. III C 2, and the appreciable differences in physical and chemical properties between light and heavy hydrogen, objections can be raised in principle against the comparison of uncorrected deuteron-proton ratios from different chemical samples. Indeed, Lindström has shown in LM50 that the two compounds used show a relative difference of $(7\pm3)\cdot10^{-6}$ in their ratios. A redetermination of $\mu(H^2)/\mu(H^1)$ from gaseous samples, where the corrections are calculable, is needed.

A start has been made recently at the theoretical study of the deuteron and proton moments, and especially of their ratio, with the aid of the new computational techniques.[16–18]

III C. Correction Factors

The six-, seven-, and possibly eight-digit data now becoming available make discussion of certain small corrections appropriate to magnetic moment measurements almost unavoidable, even in such a simple factual presentation as this table. Some of the corrections apply only to measurements made by certain methods, and some perhaps in different amount to measurements made by different methods. The general situation is still rather obscure. The discussion below will at least contribute to an understanding of the relation between the measurements reported in the table and other values that may be quoted for the same moments from the same data.

It will be helpful in the discussion below to remember that, unlike the nuclear resonance methods, the atomic and molecular beam magnetic resonance methods, and the microwave absorption method, as well as the hyperfine structure method of optical line spectra, are essentially hyperfine structure measurements, in that they measure the energy difference between two low lying states, from which the magnetic dipole moment of the nucleus can be approximately calculated.[19–25] In the discussion of the corrections it will be useful to consider together all the methods that fall in the category of hyperfine structure measurements. Hereafter in this paper they will all be called hyperfine structure methods. In the body of the table the moments obtained by nuclear resonance methods can be distinguished from those obtained by hyperfine structure methods as follows: A value from nuclear resonance measurements is marked with an uncertainty following the $\pm$ sign, without any extra symbol; while one from hyperfine structure measurements either has no uncertainty specified or is marked with the letter "*h*" after the uncertainty. No alteration, with the exception of the diamagnetic correction (footnote c), has been made in any of the values in the table; the hyperfine structure values are distinguished only for the convenience of readers who may wish to apply differential corrections (Sections III C 3 to 6).

Among the data available for the determination of nuclear dipole moments, the measurements of many of the best known species have been made both by nuclear

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TABLE I.—*Continued.*

N	Z	Atom	A	I(ħ)	μ(n.m.)	Q(e×10⁻²⁴ cm²)	References I	References μ	References Q	Atom	A
78	56	Ba	134	(0)	~0			AR50		Ba	134
79	56	Ba	135	3/2	+0.834 6 ±25*h*		MW32, HH41, AR49$_2$	*HH41*		Ba	135
80	56	Ba	136	(0)	~0 *r*			AR50		Ba	136
81	56	Ba	137	3/2	+0.935 1 ±27*h*		KA32, MW32, HH41, AR49$_2$	*HH41*		Ba	137
82	56	Ba	138	(0)	~0			AR50		Ba	138
82	**57**	La	139	7/2	+2.776 0 ±28	≠0	WH33, AO34	WK40, DK49$_2$, *CH49*	*DN49$_2$*	La	139
82	**59**	Pr	141	5/2	+4.593 8		WH29	CH50		Pr	141
83	60	Nd	143							Nd	143
85	60	Nd	145							Nd	145
85	62	Sm	147	(>1/2)			BQ49$_1$			Sm	147
87	62	Sm	149	(>1/2)			BQ49$_1$			Sm	149
88	**63**	Eu	151	5/2	+3.4 *r*	+1.2	SH35$_2$	*SH35$_2$*	*SH35$_2$*	Eu	151
90	**63**	Eu	153	5/2	+1.5	+2.5	SH35$_2$	*SH35$_2$*	*SH35$_2$*	Eu	153
91	64	Gd	155							Gd	155
93	64	Gd	157							Gd	157
94	**65**	Tb	159	3/2			SH34$_3$			Tb	159
95	66	Dy	161							Dy	161
97	66	Dy	163							Dy	163
98	**67**	Ho	165	7/2			SH35$_1$			Ho	165
99	68	Er	167							Er	167
100	**69**	Tm	169	1/2			SH34$_5$			Tm	169
101	70	Yb	171	1/2	+0.45		SH38	*SH38*		Yb	171
103	70	Yb	173	5/2	−0.65 *r*	+3.9 ±4	SH38	*SH38*	*SH38*	Yb	173
104	**71**	Lu	175	7/2	+2.6	+5.9	SH34$_2$	SH35$_2$, GL36	SH35$_2$, SH35$_3$, CC35, *GL36*	Lu	175
105	**71**	Lu	176*	⩾7	+3.8	+7 ±1	SH39	*SH39*	*SH39*	Lu	176*
105	72	Hf	177	(1/2, 3/2)			RS35			Hf	177
106	72	Hf	178	(0)	~0			RS35		Hf	178
107	72	Hf	179	(1/2, 3/2)			RS35			Hf	179
108	72	Hf	180	(0)	~0			RS35		Hf	180
108	**73**	Ta	181	7/2	+2.1	+6	GR33$_2$, GI33	*GI33*	*SC43*	Ta	181
108	74	W	182	(0)				GR34		W	182
109	74	W	183	1/2			GR34, KP48			W	183
110	74	W	184	(0)				GR34		W	184
112	74	W	186	(0)				GR34		W	186
110	**75**	Re	185	5/2	+3.3 *r*	(+2.8)	GT30, MG31, ZE31	*SH37$_2$*, SC38	*SH37$_2$*	Re	185
112	**75**	Re	187	5/2	+3.3	+2.6	GT30, MG31, ZE31	*SH37$_2$*, SC38	*SH37$_2$*	Re	187
111	76	Os	187							Os	187
113	76	Os	189	1/2			KD38			Os	189
114	**77**	Ir	191	(>1/2)	*r* >0		VS35, MW50	VS35, *MW50*		Ir	191
116	**77**	Ir	193	(3/2)			VS35, MW50	VS35, *MW50*		Ir	193
116	78	Pt	194	(0)	~0			FU35		Pt	194
117	78	Pt	195	1/2	+0.605 92 ±8		JC36, TL37	SC36, PR49$_3$, *PR50*		Pt	195
118	78	Pt	196	(0)	~0			FU35		Pt	196
119	**79**	Au	197	3/2	+0.20		ET39	*ET39*		Au	197
118	80	Hg	198	(0)	~0			TL31		Hg	198
119	80	Hg	199	1/2	+0.504 13 ±3		SH31$_2$	GQ33, SH35$_4$, MR40, PR49$_3$, *PR50*		Hg	199
120	80	Hg	200	(0)	~0			TL31		Hg	200
121	80	Hg	201	3/2	−0.559 0 ±1*h*	+0.5	SH31$_2$	GQ33, SH35$_4$, *MR40*	SH35$_2$, *SH35$_4$*	Hg	201
122	80	Hg	202	(0)	~0			TL31		Hg	202
124	80	Hg	204	(0)	~0			TL31		Hg	204
122	**81**	Tl	203	1/2	+1.611 66 ±14 *r*		SH29, SH31$_1$	GQ33, SH37$_1$, SH37$_2$, *PR49$_1$*, *PH49*, CR49$_2$		Tl	203
124	**81**	Tl	205	1/2	+1.627 50 ±14		SH29, SH31$_1$	GQ33, SH37$_1$, SH37$_2$, *PR49$_1$*, *PH49*, CR49$_2$		Tl	205
122	82	Pb	204	(0)	~0			GE50		Pb	204
124	82	Pb	206	(0)	~0			MW31		Pb	206
125	82	Pb	207	1/2	+0.589 50 ±7		KP31, CT36	GQ33, CT36, PR49$_2$, CR49$_2$, SA49		Pb	207
126	82	Pb	208	(0)	~0			MW31		Pb	208
126	**83**	Bi	209	9/2	+4.1	−0.4	GQ27	*GQ33*, *WK40*, XX50	*SH36$_1$*	Bi	209
140	**91**	Pa	231*	3/2			SH34$_1$			Pa	231*
143	92	U	235*	(5/2, 7/2)			AO47, TL50			U	235*
144	**93**	Np	237*	5/2			TP48			Np	237*

induction or resonance, on the one hand, and by atomic or molecular beam magnetic resonance (hyperfine structure) methods on the other. But in every case where both kinds of measurements have been used, the claimed accuracy is better for the nuclear induction or resonance measurements. I have avoided certain complications by neglecting the hyperfine structure measurements completely wherever measurements of both types have been reported; although this procedure has, in principle, the weakness of neglecting some independent data, the relatively slight weight of those data, coupled with the unknown possible inaccuracies in the correction factors, impels me to follow this expedient.

III C 1. The Diamagnetic Correction

This is the correction for the interaction between the nucleus and the diamagnetism of the atomic electrons: The diamagnetic interaction has the same effect on the measurements of the nuclear moment as though the (actual, in contrast with the observed) nuclear moment were multiplied by a factor, one minus a quantity approximately proportional to the four-thirds power of the atomic number. It can be taken into account by dividing the observed nuclear g factor by $1-DZ^{4/3}$, where D is given by the Fermi-Thomas model as 3.19×10^{-5}, and by the more detailed Hartree model as a somewhat smaller, slowly increasing function of Z, which has been calculated by Lamb.[26, c, cc] The diamagnetic correction is applicable, according to Lamb, to hyperfine structure measurements, and it is regularly applied to all μ-measurements upon atoms, i.e., upon nuclei surrounded by electrons, no matter by what method the moment is measured. While the effect depends upon the state of ionization of the atom, the correction is ordinarily made as a function of Z only, i.e., as though all the atoms under consideration were neutral.

III C 2. Chemical Effects

Among the reports in the recent literature on the most extraordinarily accurate measurements, there have been several comments on queer line shapes, and especially on asymmetries in lines expected to be single. The extensive literature on relaxation time studies will not be listed here. Questions have been raised as to whether the condition of chemical combination of an atom may affect the resonance frequency of the nucleus (cf., e.g., SN49). Pake has found (PA48) a doubling of the proton resonance in crystals, and Knight has found ($KG49_1$) that the frequency in a metal is higher by tenths of a percent than the frequency in a salt of the same atom. Very recently some of the asymmetric lines have been resolved into complexes, and the workers in several laboratories have independently become convinced that the observations arise, not from instrumental deficiencies, but from the influence of the state of chemical combination of the atom whose nucleus is under observation (references BL50, XX50, BI50). The splittings recognized so far have relative values all the way from 10^{-5} to 5×10^{-3}, and appear to be at least roughly proportional to the external field strength; the latter value has been found (reference PR50) in $_7$N, where an aqueous solution of NH_4NO_3 gives two signals separated by 5.3 gauss in 1.05×10^4 gauss, and experiments with other compounds show that the ammonium radical yields higher apparent values for $\mu(_7N)$ than the nitrate radical.[d] Beyond giving a warning as to its effect on the recognized uncertainty of the μ-values, it is too early to discuss the chemical effect extensively. Ramsey emphasizes that the separation of the chemical effects from the diamagnetic effects is artificial.

[26] W. E. Lamb, Phys. Rev. **60**, 817 (1941).

[c] The following values have been used in Table I; the value for $_1$H and that for $_2$H are discussed in footnote cc, and the rest are from Lamb[26] or from the linear interpolation (or for $_{81}$Tl and $_{82}$Pb, extrapolation from $_{74}$W and $_{80}$Hg) of D. Parentheses indicate that a diamagnetically corrected value was taken from reference PR50; while the correction was made by the same process as used here so that the value of the correction was presumably the same as the value given here, I have not had access to the data for verification. The long interpolation between $Z=1$ and $Z=19$ is certainly a rather crude procedure, but the corrections it yields are rather small compared with those for the heavier atoms. Throughout the list, for convenience in expressing the internal consistency of the measurements (see Section III D) the correction is sometimes carried to more places than are justified by our knowledge of the magnitude of the diamagnetic correction:

TABLE (c). Diamagnetic correction values used in Table I.

Z	$D\cdot10^5$	Correction factor	A	Correction added, n.m.
0	--	1 exactly		0 exactly
1	3 ±2	0.999 97	1	0.000 084
			2	0.000 026
			3	0.000 089
2	2.8	0.999 930, footnote cc.	3	0.000 149
3	1.87	0.999 919 2	6	0.000 07
			7	0.000 26
4	1.915	0.999 878 5	9	0.000 143
5	1.960	0.999 832	10	0.000 30
			11	0.000 45
6	2.005	0.999 802	13	0.000 14
7	2.050	0.999 744	14	0.000 10
			15	0.000 07
9	2.140	0.999 611	19	0.001 0
11	2.230	0.999 456	22	0.000 95
			23	0.001 21
13	2.320	0.999 282	27	0.002 61
15	2.410	0.999 088	31	0.001 03
17	2.500	0.998 877	35	0.000 92
			37	0.000 77
19	2.590	0.998 687	39	0.000 5
			40	0.001 7
			41	0.000 3
23	2.610	0.998 293	51	0.008 8
25	2.623	0.998 083	55	(0.006 6)
27	2.645	0.997 858	59	(0.010 0)
29	2.680	0.997 612	63	0.005 32
			65	0.005 69
31	2.684	0.997 387	69	0.005 3
			71	0.006 7
35	2.695	0.996 916	79	0.006 5
			81	0.007 0
36	2.697	0.996 800	83	0.003 1
37	2.700	0.996 671	85	0.004 50
			87	0.009 15
47	2.722	0.995 38	107	0.000 4
			109	0.000 8
48	2.724	0.995 248	111	(0.002 83)
			113	(0.002 96)
49	2.727	0.995 110	113	0.026 8
			115	0.026 9
50	2.729	0.994 973	115	(0.004 61)
			117	(0.005 02)
			119	0.005 26
53	2.736	0.994 553	127	0.005 30
			129	0.014 9
55	2.740	0.994 269	133	0.014 8
			135	0.015 6
			137	0.016 3
56	2.742	0.994 125	135	0.004 9
			137	0.005 5
57	2.743	0.993 983	139	0.016 7 2
78	2.790	0.990 702	195	(0.005 63)
79	2.795	0.990 526	197	(0.001 9)
80	2.800	0.990 349	199	(0.004 86)
81	2.805	0.990 170	203	0.015 84
			205	0.016 00
82	2.810	0.989 989	207	0.005 90

[cc] *Note added in proof February, 1950:* N. F. Ramsey [Phys. Rev. **77**, 567 (1950)] points out that neither the Lamb atomic diamagnetic correction factor (reference 26, Eq. (6)) of 0.999 982 2 for hydrogen, nor the helium-like approximation of Anderson (AN48), which yields a factor 0.999 967 6, is exactly applicable to the experiments on molecules. Ramsey proposes a theoretical factor incorporating the spin-rotational interaction of the molecule and equal to 0.999 972 9 for H_2 gas. Unfortunately the experiments up to now have been carried out only with other substances (cf. Table II), although one is to be done with H_2 gas (HP50). The important but difficult case of the boomerang-shaped water molecule has not yet been solved. At present, then, the principal use of Ramsey's equation is to serve as a warning agginst claims to too great accuracy in the application of diamagnetic corrections. In this paper the Anderson value for helium, and a compromise value approximating that of Ramsay for hydrogen, are used consistently, but all other atoms are calculated on Lamb's basis.

[d] Because of the chemical effect it becomes important to record the compound upon which a measurement is made. Corresponding to the accounts generally found in the original literature, the following list shows the compounds used, presumably in water solution, for the measurements reported under reference PR50:

$_7N^{14}$: HNO_3	$_{48}$Cd: $CdCl_2$
$_7N^{15}$: NH_3	$_{50}$Sn: $SnCl_2$
$_{17}$Cl: HCl	$_{78}$Pt: H_2PtCl_6
$_{23}$V: $NaVO_3$	$_{80}$Hg: $HgNO_3$
$_{25}$Mn: $LiMnO_4$, $KMnO_4$	$_{81}$Tl: $Tl(C_2H_3O_2)$
$_{27}$Co: $K_3Co(CN)_6$	$_{82}$Pb: $Pb(C_2H_3O_2)_2$

A higher-order chemical effect, namely the dependence of the resonance frequency ratio of two isotopes of the same element, upon the chemical combination, is exhibited in the two LM50 items in Table II.

III C 3. The Radiative Correction

The radiative correction is necessary on account of the behavior of the electron as though its mass depended upon the nature of the field present: Schwinger[27] and Luttinger[28] have reconciled the measured discrepancy between the ratio of the hyperfine structure splitting and the ratio of the magnetic dipole moments for the isotopes of hydrogen and several other elements[e, 29–31] in terms of a radiative correction factor $(1+\alpha/2\pi)=1.001\,162$ in the magnetic moment associated with electron spin. Here α is the fine-structure constant, equal to approximately 1/137. Division of an observed hyperfine structure value (which measures the interaction between the nucleus and the magnetic moment of the extranuclear electrons) by this factor ought, according to this interpretation, to make it consistent with the values obtained by nuclear resonance methods.

III C 4. Relativistic Effects

An electron moving rapidly in a force field has, on account of relativistic effects, a slightly different moment, and consequently contributes differently to the hyperfine structure of an atom, from a free electron. Breit[32] has discussed the magnetic moment of a heavy atom. Margenau[33] finds a correction arising from the rapid motion of a charged particle in a central field, which for an *s*-electron amounts to $(1-Z_0{}^2\alpha^2/3n_{\mathrm{eff}}{}^2)$, where $Z_0{}^2/n_{\mathrm{eff}}{}^2$ is the ionizing potential of the atom in Rydberg units. This effect has a relative value of the order of 10^{-5} in typical cases. For single non-*s* electrons, values may be read out of Margenau's Eq. (4).

III C 5. Reduced Mass Effect

Breit and his co-workers[34–35] have shown that the motion of the nucleus yields a contribution of the order of $(1+m/M)^{-3}$ to the hyperfine structure and a quantity that appears to be of the order of 10^{-8} to the fine structure of hydrogen, where m and M are the masses of the electron and the nucleus, respectively. It has become customary, and helps toward making the hyperfine structure measurements agree with nuclear resonance methods, although it does not appear to have been formally justified, to apply the $(1+m/M)^{-3}$ factor to isotope pairs of heavier atoms. $(1+m/M)^{-3}$ yields a correction of 8×10^{-4} between H^1 and H^2, and of the order of 4×10^{-4} between Li^6 and Li^7, and of 2×10^{-6} between K^{39} and K^{41}.

TABLE II. The deuteron-proton moment ratio.

Reference	Sample	μ_2/μ_1	Weight
RU47	water	0.307 002 $\pm$0.000 014	7
BL47$_3$	water	0.307 012 6$\pm$0.000 002	50
BI47	liquid H_2	0.307 021 $\pm$0.000 005	20
WJ49	water	0.307 011 7$\pm$0.000 001 7	59
SN49	water	0.307 018 3$\pm$0.000 001 5	67
ZI49	water	0.307 10 $\pm$0.000 1	1
SR50	water	0.307 012 2$\pm$0.000 001 4	71
LM50	paraffin oil	0.307 016 5$\pm$0.000 000 5	200
LM50	water	0.307 014 3$\pm$0.000 000 5	200
	Weighted mean	0.307 015 0	

III C 6. Nuclear Size and Structure Effects

Rosenthal and Breit[36] have found that the energy levels of an atom depend quite appreciably upon the extent of the nucleus even when the nucleus is spherically symmetric. In contrast with this size effect, which is primarily of importance for heavier (larger) nuclei Bohr[37] has called attention to a structure effect which can be important even for the lightest nuclei. This effect arises because of the spatial extension of the nuclear magnetic moment, and depends on the way in which the magnetic moment is distributed among the nuclear particles. In the case of Rb, where the two odd isotopes ${}^{50}{}_{37}Rb^{87}$ and ${}^{52}{}_{37}Rb^{89}$ have ground states with different spin and there are indications of shell completion,[38–40] Bitter[41] calls attention to the presence of a hyperfine structure anomaly where it is highly improbable that there can be enough size difference to account for it; thus it is emphasized that structural effects, i.e., the distribution of the moment, have an influence at least comparable with the size effect. In rubidium the relative magnitude of the hyperfine structure-magnetic moment anomaly is of the order of 3×10^{-3}.

[27] J. Schwinger, Phys. Rev. **73**, 416 (1948); **76**, 790 (1949).

[28] J. M. Luttinger, Phys. Rev. **74**, 893 (1948).

[e] Hyperfine structure-dipole moment anomalies or atomic *g*-value anomalies have been studied in the following elements:

H	References 29, 30
Li, Na, K, Rb, Cs	Reference KU49$_2$
Na, Ga	Reference 31
Na, Ga, In	References KU48, MD50
Cl	References DI49$_1$, PR50
Tl	Reference BH50.

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III D. The Uncertainty in the μ-Values

The uncertainty value assigned to each dipole moment is by no means the whole uncertainty in the determination of the value. Usually it is the uncertainty (probably approximately the standard deviation) assigned to the value by an author from internal consistency tests alone, although where several authors disagree beyond the range of their assignments I have increased the value. Such increases are small except in the case of Be^9, where I have assigned $\pm 8\times 10^{-4}$ although one of the two authors quotes hardly one-fiftieth of that. No allowance is made for systematic errors, and in particular, although the diamagnetic correction has been made according to Section III C 1 and footnote c, no allowance has been made for any other effects, Sections III C 2 to III C 6. For the best measured values it would hardly be safe at present to assign a relative uncertainty less than about 10^{-3} for the chemical effect alone. Any value given without $\pm$ assignments, i.e., never assigned uncertainties by its author or in this study, is probably good approximately to its penultimate digit.

A bracketed pair of values, with the symbol r at the vertex of the bracket, has a ratio somewhat better known than the individual values; its value may be found, usually, in a reference common to both, and always in a reference listed for at least one. In the one case of a bracket that appears without an r, Hg, the ratio was used in the determination of the moment of one of the isotopes. The symbol "$r>0$" at Ir, means that the moments have been reported to have the same sign.

IV. THE QUADRUPOLE MOMENT, Q

The quadrupole moments listed, although several of them have been given uncertainties of the order of one percent, can hardly be considered anything more than indications. They have been determined by several apparently inconsistent methods, and widely different values have been reported from the same data. Consideration was given to the project of studying all the quadrupole moment data from a unified viewpoint, but it has been abandoned for this table.

Brackets and r, for those instances where the ratio of the quadrupole moments is known, have been used as in the μ-column.

In spite of some positive findings by Tolansky,[42] the evidence for octopoles and magnetic quadrupoles is inconclusive (references BG48, $DI49_3$).

V. THE LITERATURE

The literature in the table is not complete. An attempt has been made, however, to record at least the first paper announcing the value of a "correct" spin and enough very recent papers, in each case that has been worked on recently, in order to provide a consensus and give the reader an opportunity to work backward through the late references cited. In general the literature symbols on the spin moment are not italicized, and papers showing clearly wrong spin values have been omitted. In the dipole and quadrupole moment columns the literature used in evaluations has been italicized in case some values have been preferred over others.

References preceded by a *c* indicate that the reference in question was used in the calculation of the moment under consideration, although the reference itself does not give a value for the quantity in question.

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VI. ACKNOWLEDGMENTS

Before submitting this table for publication, I sent a preliminary draft of it to about 30 former or present workers in the field, with a request for corrections and comments. (That draft is now quite obsolete, especially because the μ-values have all been recalculated following HP49.) The generous response to the request makes the list of acknowledgments long; incidentally, the fact that most of the omissions in the draft were pointed out by several persons makes me fairly confident that there are no major omissions left.

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AR48	O. H. Arroe, Phys. Rev. **74**, 1263 (1948)	Zn	S
$AR49_1$	O. H. Arroe and J. E. Mack, Phys. Rev. **76**, 873 (1949)	Zr	S
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BF34 S. S. Ballard, Phys. Rev. **46**, 806 (1934) — Nb — S

BG48 G. E. Becker and P. Kusch, Phys. Rev. **73**, 584 (1948) — Ga — A

BH50 Berman, Kusch, and Mann, Phys. Rev. **77**, 140 (1950) — Tl — A

BI47 Bitter, Alpert, Nagle, and Poss, Phys. Rev. **72**, 1271 (1947) — H — R

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KR28	R. Kronig, Naturwiss. **16**, 335 (1928)	N	B
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ML35	S. Millman, Phys. Rev. **47**, 739 (1935)	K	A
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