Nuclear Moments and Moment Ratios as Determined by Mössbauer Spectroscopy*

J. G. Stevens

University of North Carolina, Asheville, North Carolina 28804

and

B. D. Dunlap

Argonne National Laboratory, Argonne, Illinois 60439

Values are given for Mössbauer effect measurements of nuclear magnetic moments, spectroscopic quadrupole moments, ratios of moments between low lying excited states and the ground state of the same isotope, and ratios of moments between states of different isotopes. Adopted values for moments, obtained by direct selection of specific results or by an averaging process, are presented. The literature has been covered through December, 1974.

Keywords: Mössbauer; nuclear electric quadrupole moments; nuclear magnetic dipole moments.

Contents

1. Introduction

For general discussions of Mössbauer spectroscopy, the reader is referred to a number of review articles in [Go68].[1] For the present purposes, we will make only a few introductory comments.

Measurements of hyperfine interactions obtained by Mössbauer spectroscopy differ from other methods in that one obtains hyperfine energy differences between the nuclear ground state and some excited state, rather than values for a single nuclear level. While ground state moments are generally determined more accurately by other methods, not many techniques are widely applicable to measurements of excited state moments. Therefore, the application of the Mössbauer effect to the measurement of nuclear moments has been widespread.

If a magnetic hyperfine field H_{hf} is present at the nucleus, then one measures in a Mössbauer spectrum a set of energy value differences given by

$$\begin{aligned}\Delta E_{\mathrm{M}}(I_z^*, I_z) &= -g_{\mathrm{N}}^*\mu_{\mathrm{N}}I_z^*H_{\mathrm{hf}} + g_{\mathrm{N}}\mu_{\mathrm{N}}I_zH_{\mathrm{hf}},\\ &= -g_{\mathrm{N}}\mu_{\mathrm{N}}H_{\mathrm{hf}}\left[\frac{g_N^*}{g_{\mathrm{N}}}I_z^* - I_z\right], \qquad (1)\\ &= -\mu\mu_{\mathrm{N}}H_{\mathrm{hf}}\left[R_\mu\frac{I_z^*}{I^*} - \frac{I_z}{I}\right],\end{aligned}$$

where I^* and I are the excited and ground state nuclear spins, $I_z{}^*$ and I_z are components of I^* and I in the direction of the hyperfine field, μ_{N} is the nuclear magneton, $g_{\mathrm{N}}{}^*$ and g_{N} are the nuclear gyromagnetic ratios in the excited and ground states, and R_μ is the ratio of nuclear magnetic moments

$$R_\mu = \frac{\mu^*}{\mu} = \frac{g_{\mathrm{N}}{}^*\,I^*}{g_{\mathrm{N}}\,I}. \qquad (2)$$

Depending on the selection rules governing the nuclear transitions between the $(2I_z^* + 1)$ excited state and $(2I_z + 1)$ ground state levels, one measures a number of such energies, each appearing as an absorption line in the resonance spectrum. A specific example is given in figure 1 where the magnetic hyperfine splitting is shown for a case having $I = 1/2$ and $I^* = 3/2$ applicable, for example, to the Mössbauer resonance in ^{57}Fe or ^{119}Sn. Dipole selection rules allow six possible transitions with the energies shown in the figure. One sees here, or from eq (1), that the relative line positions depend only on the ratio R_μ. This quantity is thus obtained with no external assumptions, and in most cases it is the basic nuclear magnetic moment information provided by the experiment. The ground state moment, if known from other measurements, can then be combined with this ratio to obtain the excited state moment.

---

[1] Symbols in brackets indicate literature references.

*Work supported by the U.S. Energy Research and Development Administration, the Office of Standard Reference Data of the National Bureau of Standards, the Petroleum Research Fund, administered by the American Chemical Society, and the Research Corporation.

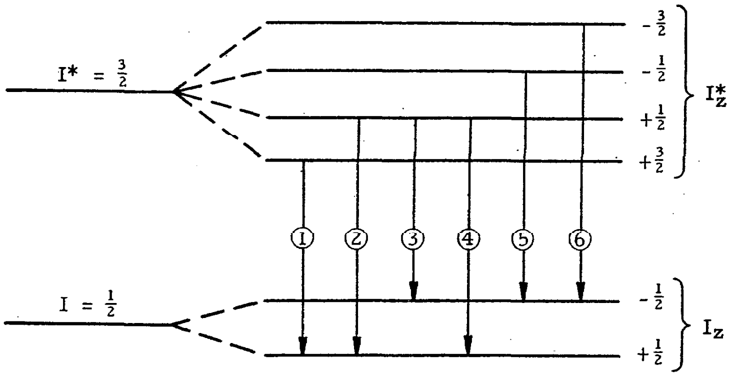
The absolute line positions, rather than the relative positions, depend on the product of the moments and the hyperfine field. If H_{hf} is known from other measurements or by calculation, then these positions can be used to determine the moment values. This approach has been used especially for even-even nuclei where $I_z = 0$. Since in this case the ground state moment is zero, one measures only the excited state splitting, and no moment ratio. Some discussion of H_{hf} is thus necessary in order to obtain the excited state moment.

If an electric field gradient is present at the nucleus, then electric quadrupole hyperfine splitting may occur. In a manner similar to the above, a measurement of the quadrupole resonance spectrum can provide the ratio of spectroscopic quadrupole moments $R_Q = Q^*/Q$. This is illustrated in figure 2 for a case where $I = 5/2$ and $I^* = 7/2$ as, for example, in ^{121}Sb or ^{151}Eu. If information concerning the electric field gradient tensor is available, the absolute line positions provide the quadrupole moments directly. Most often this latter approach relies on calculations of the field gradient, which in some cases can be done with reasonable reliability. However, it is important to realize that large "Sternheimer corrections" may be necessary due to a shielding of the field gradient at the nucleus by the local electrons (see [St76a]). In many cases, the magnitude of this shielding is not well known, and this may cause a large error in the derived quadrupole moment.

Moment ratios and moments obtained as described above are listed in table 1, covering all the available measurements through December 1974. We emphasize that we consider ratios of moments measured by the Mössbauer technique to be the most fundamental experimental quantities since they are obtained without the need of other data. In general, however, we have also given ground state moments obtained from other works and used the listed ratios to obtain excited state moments.

Frequently in the literature measurements of hyperfine energies have been obtained using two different isotopes in the same compound. If the ratio of these energies is calculated, the hyperfine field or electric field gradient cancels and one obtains a ratio of the nuclear moments of those isotopes. This may then be combined with a measured value for one of the moments to obtain the other. Ratios obtained in this way are listed in table 2. These are also cross-referenced to an entry in table 1 where the ratio is used to obtain one of the moments.

Table 1 also indicates adopted values for the ratios and moments. When one measurement appears to be substantially more reliable than other published results due to superior data or analysis, that value has been chosen as the adopted value. In the majority of cases, several measurements of comparable quality exist and an averaging procedure over selected values has been used. Again here, the choice of which values to include in averaging is based on quality of data and of analysis. The final adopted values are summarized for convenience in table 3.



① $\Delta E_M(\frac{3}{2}, \frac{1}{2}) = -\mu\mu_N H_{hf}[R_\mu - 1]$

② $\Delta E_M(\frac{1}{2}, \frac{1}{2}) = -\mu\mu_N H_{hf}[\frac{1}{3}R_\mu - 1]$

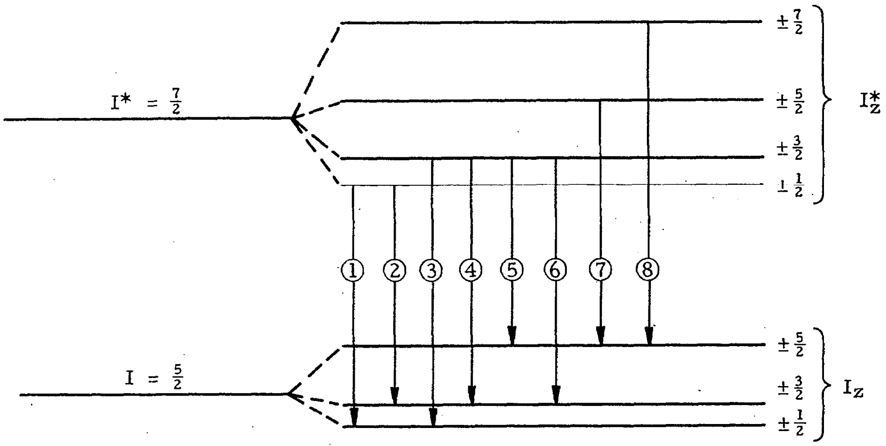
③ $\Delta E_M(\frac{1}{2}, -\frac{1}{2}) = +\mu\mu_N H_{hf}[-\frac{1}{3}R_\mu - 1]$

④ $\Delta E_M(-\frac{1}{2}, \frac{1}{2}) = -\mu\mu_N H_{hf}[-\frac{1}{3}R_\mu - 1]$

⑤ $\Delta E_M(-\frac{1}{2}, -\frac{1}{2}) = +\mu\mu_N H_{hf}[\frac{1}{3}R_\mu - 1]$

⑥ $\Delta E_M(-\frac{3}{2}, -\frac{1}{2}) = +\mu\mu_N H_{hf}[R_\mu - 1]$

FIGURE 1. Magnetic hyperfine splitting and resonance line positions for $I^* = 3/2 \rightarrow I = 1/2$ transition. In the splitting diagram, the energy level ordering presumes positive values of μ and μ^*.



① $\Delta E_Q(\pm\frac{1}{2}, \pm\frac{1}{2}) = e^2qQ[-\frac{5}{28}R_Q + \frac{1}{5}]$

② $\Delta E_Q(\pm\frac{1}{2}, \pm\frac{3}{2}) = e^2qQ[-\frac{5}{28}R_Q + \frac{1}{20}]$

③ $\Delta E_Q(\pm\frac{3}{2}, \pm\frac{1}{2}) = e^2qQ[-\frac{3}{28}R_Q + \frac{1}{5}]$

④ $\Delta E_Q(\pm\frac{3}{2}, \pm\frac{3}{2}) = e^2qQ[-\frac{3}{28}R_Q + \frac{1}{20}]$

⑤ $\Delta E_Q(\pm\frac{3}{2}, \pm\frac{5}{2}) = e^2qQ[-\frac{3}{28}R_Q - \frac{1}{4}]$

⑥ $\Delta E_Q(\pm\frac{5}{2}, \pm\frac{3}{2}) = e^2qQ[\frac{1}{28}R_Q + \frac{1}{20}]$

⑦ $\Delta E_Q(\pm\frac{5}{2}, \pm\frac{5}{2}) = e^2qQ[\frac{1}{28}R_Q - \frac{1}{4}]$

⑧ $\Delta E_Q(\pm\frac{7}{2}, \pm\frac{5}{2}) = e^2qQ[\frac{1}{4}R_Q - \frac{1}{4}]$

FIGURE 2. Electric quadrupole hyperfine splitting and resonance line positions for $I^* = 7/2 \rightarrow I = 5/2$ transition. The principal component of the electric field gradient tensor is $V_{zz} = eq$, and axial symmetry is assumed. In the splitting diagram, the energy level ordering presumes positive values of Q and Q^*.

2. Error Analysis and Averaging Procedure

Uncertainties, given in parentheses beside the data values, show estimated deviation for the indicated number of trailing significant figures. Thus, 1.065(40) = 1.065 ± 0.040. For ratios of moments, uncertainties quoted are those of the original reference. If no value was given there, then none appears here. Moment values X_1 are generally obtained by combining a measured ratio R with a measured value for another moment X_2, i.e., $X_1 = RX_2$. Uncertainties ΔX_1 are then determined by

$$\left(\frac{\Delta X_1}{X_1}\right)^2 = \left(\frac{\Delta R}{R}\right)^2 + \left(\frac{\Delta X_2}{X_2}\right)^2, \qquad (3)$$

where ΔR and ΔX_2 are measured uncertainties. If no value is available for either ΔR or ΔX_2, then none is given for ΔX_1. In cases where the moment is not obtained by a ratio, the stated uncertainty is that of the original reference. Averaging has been performed by weighting the measured quantities by the inverse square of the error:

$$X = (\Sigma\sigma_i^{-2}X_i)/(\Sigma\sigma_i^{-2}) \qquad (4)$$

where $\sigma_i = \Delta X_i$. The probable error $\Delta\bar{X}$ assigned to the average, has been calculated both according to

$$(\Delta\bar{X})^2 = [\Sigma\sigma_i^{-2}]^{-1}, \qquad (5)$$

and

$$(\Delta\bar{X})^2 = [\Sigma\sigma_i^{-2}(X_i - \bar{X})^2] \,/\, [(N-1)\Sigma\sigma_i^{-2}], \qquad (6)$$

where N is the number of measurements used. The tabulated value for $\Delta\bar{X}$ is the larger of the two. If a value was used in averaging which had no indicated error, then for these purposes it was assigned an error equal to ±5 in the reported last significant digit.

R_μ A numerical entry indicates a value for the ratio of the magnetic moment of the excited state in question to that of the ground state for the same isotope. In some cases, the derived excited state moment and the assumed ground state moment were given, but not the actual ratio. In those cases (marked by footnote d), the ratio has been derived from the excited and ground state moments and is entered here as the experimental result. References to ratios of moments between different isotopes of the excited state in some level other than the ground state are indicated in this column by a number preceded by an r (e.g., r33), and all such measured values are listed separately in table 2 under this code number. When listed, moment ratios are to be considered the primary experimental data, with other quantities being derived results.

μ All magnetic moments are in units of nuclear magnetons ($\mu_N = 5.050824(20) \times 10^{-27}$ JT^{-1}). Ground state moments are usually obtained by some method other than Mössbauer spectroscopy, but are listed for completeness. This is not intended to be a complete listing of ground state moments, and we only include those here which are used in combination with a measured ratio. All values have been corrected for diamagnetic shielding using Kopfermann's calculations (H. Kopfermann *Nuclear Moments* (translated by E. E. Schneider), Academic Press Inc., New York, 1958). A 5 percent uncertainty was assumed for the diamagnetic shielding correction. When a value for R_μ is listed, the moment has been obtained by combining that ratio with the ground state moment listed in the table. In many cases, the resultant moment differs somewhat from that of the original reference due to the use of a more recent ground state value or our use of the diamagnetic correction. Moments obtained from ratios other than that of the ground to excited state are arrived at by combining the numerical ratio values listed in table 2 with either a ground state moment from this table, or another adopted value from table 3.

R_Q A numerical entry indicates a value for the ratio of the spectroscopic quadrupole moment in the excited state to that of the ground state in the same isotope. Conventions and notation are the same as for R_μ.

Q All quadrupole moments are in units of barns (1 barn $= 10^{-28}$ m^2). In all cases, the value listed is the spectroscopic quadrupole moment rather than the intrinsic moment. Unless noted by footnote (u), values are given after correction for the Sternheimer effect. Conventions, notations and provisions are the same as for μ.

References

References to measurements obtained by techniques other than Mössbauer spectroscopy are enclosed in parentheses. Example: (Sc70). If more than one reference is enclosed in parentheses, then the quoted value is a weighted average over all those references. Example: (Ku61, Fe63).

If the same quantity is reported more than once by the same group of authors, all references are given, but the tabulated value is taken as the latest one. Example: Do61, Lo62.

Table 1. Nuclear moment data from Mössbauer spectroscopy

Isotope	Energy	Spin	R_μ	μ	R_Q	Q	Reference
^{57}Fe	0	1/2		+0.090604 (9)			(Sc70)
	14.4	3/2				-0.19[g]	Be60a
			-1.69(5)[d]	-0.153 (5)			Ha60a
			-1.694 (20)[d]	0.1535 (18)			Ki60
						+0.100(25)[g,u]	Ab61
						+0.4[g]	Bu61
						0.32 (6)	Ga62
						> 0	Ka62
						0.18[g]	De61, La62
			-1.715 (4)[a]	-0.1554 (4)			Pr62
						+0.28[g]	We61, We62
			1.69[d]	0.153			Ch63
						+0.15 (1)[g,u]	Ei63
						+0.23 (5)[g]	Fr63
			1.69 (14)	0.153 (13)			Ni63
						+0.28[g]	St63
			-1.724 (10)	-0.1562 (9)			Gr64a
						0.34[g]	On64
						0.277[g]	Sh64
			-1.715 (2)[a]	-0.1554 (2)			Ko65
			1.7135 (15)[a]	0.15525 (14)			Pe65
			1.715 (3)[a]	0.1554 (3)			Cr67
			-1.712 (13)	-0.1551 (12)			Ei67
						+0.18[g,u]	Jo67, Jo68
			1.711 (4)[a]	0.1550 (4)			Ke67
						+ 0.20[g]	No67
						0.25[g]	Wi67
						0.175 (20)[g]	Ha68
						+ 0.283 (35)[g]	Ar68, Mu68a
						0.24 (4)[g]	Ra68
			1.7142 (33)[a]	0.15531 (30)			So68
			1.701 (8)	0.1541 (7)			Ze68

Table 1. Nuclear moment data from Mössbauer spectroscopy--continued.

Isotope	Energy	Spin	R_μ	μ	R_Q	Q	Reference
^{57}Fe	14.4	3/2				+ 0.21 (3)[a,g]	Ch69, Ch69b
			- 1.715 (4)[a]	- 0.1554 (4)			F069
						+ 0.21 (3)[a,g]	In64, In69
			1.7128 (13)[a]	0.15519 (12)			La70
						0.22 (6)[g]	Ra70
						0.20 (3)[a,g]	Ro70, Ro70a
			1.714 (5)[a]	0.1553 (5)			Sw70
						0.16 (3)[a,g]	Ba71
						0.18 (2)[a,g]	Fr70, Fr71
						+ 0.213 (5)[a,g]	Mc71, Mc71a
						0.19[g]	Se71
			- 1.7145 (5)[a]	- 0.15534 (5)			Vi71
						0.24[g]	Va72
						0.16 (3)[g]	Ha73
						+ 0.20 (3)[a,g]	Tr73
						0.20[g]	Sp74
			- 1.7142 (4)[b]	- 0.15532 (4)[b]		+ 0.209 (5)[b]	
	136.5	5/2	- 10.8 (11)[d]	- 0.98 (10)[g]			He67b
^{61}Ni	0	3/2		- 0.7498 (1)			(Dr64)
						+ 0.162 (15)	(Ch68)
	67.4	5/2	- 0.64 (20)	+ 0.48 (15)			We61a
			- 0.577 (25)[a]	+ 0.433 (19)			Er68
			- 0.563 (82)	+ 0.422 (61)			Sp68, Tr68
			- 0.637 (42)	+ 0.478 (31)			Er69
						< 0	Er69a
			- 0.640 (8)[a]	+ 0.480 (6)	- 1.21 (13)[c]	- 0.20 (3)[c]	Go71
			- 0.642 (10)[a]	+ 0.481 (7)	0.3 (9)	0.05 (15)	Lo68, Lo68a, Lo68b, Lo71
			- 0.637 (11)[b]	+ 0.478 (7)[b]			
^{67}Zn	0	5/2		+ 0.8755 (3)			(Sp67, Sp67a, We53)
	93.3	1/2	+ 0.66 (3)[d]	+ 0.58 (3)			Pe73, Pe73a
^{83}Kr	0	9/2		- 0.9703 (2)			(Br68)
						+ 0.253 (7)[u]	(Ku61, Fa63)

Table 1. Nuclear moment data from Mössbauer spectroscopy--continued.

Isotope	Energy	Spin	R_μ	μ	R_Q	Q	Reference
^{83}Kr	9.4	7/2			$1.70(2)^{c}$	$+0.430(13)^{c,u}$	Ru66
			$+0.971(2)^{c}$	$-0.943(2)^{c}$			Ca69
					1.98	0.50^{u}	Kr69
			1.03 (6)	−0.99 (8)			Gr69
^{99}Tc	0	9/2		+5.6807 (14)			(Wa52)
						$+0.34(17)^{u}$	(Ke53)
	140.5	7/2	$+0.64(16)^{d}$	+3.6 (8)			Sh73
^{99}Ru	0	5/2		−0.626 (13)			(Ma65, Gi73a)
						$0.12(3)^{f}$	Ba72a, Gi74
	89.3	3/2	0.455 (10)	$-0.284(8)^{a}$	≥ 3	$\geq 0.15^{g}$	Ki64a, Ki66
				$-0.30(3)^{g}$			Ki66
					r1	$0.36(7)^{c}$	Ba72a
			$0.456(2)^{c}$	$-0.285(6)^{a}$	$+2.88(6)^{c}$	> 0.23	Gi73, Gi74
				$-0.285(5)^{b}$			Gi73a
^{119}Sn	0	1/2		−1.0461 (3)			(Pr50)
	23.8	3/2	0.75 (6)	+0.78 (6)			Ha60
			$0.80(3)^{d}$	0.83 (3)			Bo61
			$-0.648(25)^{d}$	+0.68 (4)			Ki61
			$-0.72(3)^{d}$	+0.75 (3)			De60, Br62
						$-0.08^{g,u}$	Bo62
						$0.05^{g,u}$	Co64c
			−0.68	+0.71			He64
				0.67 (1)			Go65, Go65a
				0.685 (15)			Bo66
			0.652	0.68			Ku66
			0.70 (2)	0.73 (2)			Ja67
						$-0.06(2)^{g,u}$	Ru67c
			−0.64 (1)	+0.67 (1)			Wi68
						$-0.122^{g,u}$	De70a
			$0.658(3)^{d}$	0.688 (3)			Bo71, Bo71a
			−0.6462 (6)	+0.676 (7)			No71, Ba72
						$-0.062(20)^{a,g,u}$	Ba72a

Table 1. Nuclear moment data from Mössbauer spectroscopy--continued.

Isotope	Energy	Spin	R_μ	μ	R_Q	Q	Reference
^{119}Sn	23.8	3/2			r2	± 0.062 (5)[a,u]	Mi72, Ba73
			-0.615 (9)[a]	+ 0.643 (9)			Br73, Wi73
			-0.6045 (15)[a]	+0.6324 (15)			Cr73, Cr73a
			-0.605 (17)[b]	+0.633 (18)[b]		-0.065 (5)[b,u]	
	89.5	11/2		1.40 (8)			Gu72
					r3	-0.14 (2)	Be72
^{121}Sb	0	5/2		+ 3.3591 (6)			(Co50, Pr51)
						-0.28 (6)[f,g,u]	Ru67c
	37.2	7/2			1.38 (2)	-0.39 (8)[u]	Sn66, Ru66a
					1.36 (2)	-0.38 (8)[u]	Ru67
			+ 0.700 (9)[d]	+2.35 (3)			Ru67, Ru67b
			0.748 (9)[a,d]	2.51 (3)			Ru67a
					1.32 (2)	-0.37 (8)[u]	St70a
			0.729 (6)[a,d]	2.45 (2)[a,g]			Ir70, Ir70a
					1.34 (1)[c]	-0.38 (8)[c,u]	St70
			+0.735 (9)[b]	+ 2.47 (3)[b]			
^{125}Te	0	1/2		-0.88716 (25)			(We53)
	35.5	3/2		+ 1.92[g]		-0.16[a,g,u]	Sh63
						0.20 (3)[a,g,u]	Vi63
					r4	-0.24[a,u]	Pa67
			-0.84 (9)[a]	+ 0.75 (8)			Ul67
			-0.678 (23)[a,d]	+ 0.60 (2)			Hu64, Fr65, Fr68
						> 0	Ku69
						< 0[a]	Ch74
			-0.69 (6)[b]	+0.61 (5)[b]		-0.200 (23)[b,u]	
^{127}I	0	5/2		+ 2.8091 (4)			(Po48, Zi49, Sh51, Wa51, Ya51)
						-0.79 (10)[u]	(St59)
	57.6	7/2			-0.896 (2)[c]	-0.71 (9)[c,u]	Pe64a
			0.905 (16)[c]	2.54 (4)[c]			Wo72a
^{129}I	0	7/2		+2.6174 (8)			(Wa51)
						-0.55 (7)[u]	(Li53)

Table 1. Nuclear moment data from Mössbauer spectroscopy--continued.

Isotope	Energy	Spin	R_{μ}	μ	R_Q	Q	Reference
^{129}I	27.8	5/2	+1.085(19)^{d}	+2.84(5)			De64
					+1.23(2)	-0.68(9)^{u}	De63, Ha64
					+1.234(3)^{a}	-0.68(9)^{u}	Pa65
			1.0687(11)^{c}	+2.797(3)^{c}			De70
					1.2385(11)^{a}	0.68(9)^{u}	Ro72
					1.239(7)	0.68(9)^{u}	Ba74
					+1.2380(15)^{b}	-0.68(6)^{b}	
^{129}Xe	0	1/2		-0.77682(23)			(Br68)
	39.6	3/2			r5	-0.41(4)^{c}	Pe64
			-0.87(39)	+0.68(30)			Ca68
			-0.75(12)^{c}	+0.58(9)^{c}			Va74
^{133}Cs	0	7/2		+2.5786(8)			(Wh73)
						-0.0030(7)	(St71, Ry72)
	81.0	5/2	+1.335(8)^{c}	+3.443(21)^{c}			Ca68, Ca68a
			1.36(3)	3.51(8)			Ge72
^{141}Pr	0	5/2		+4.162(2)			(Le70a)
						-0.059(4)^{u}	(Bl64)
	145.2	7/2	$+0.67(^{3}_{2})^{a}$	$+2.80(^{12}_{6})$		$< 0.3^{u}$	Be71a
			+0.67(4)^{a}	+2.80(18)			Ka71, Ka71a
			+0.750(45)^{a}	+3.12(18)			Gr73
			+0.69(2)^{b}	+2.87(9)^{b}			
^{145}Nd	0	7/2		-0.654(4)			(Sm65)
	72.5	5/2	+0.489(4)	-0.320(3)			Ka68, Ka70b
^{147}Pm	0	7/2		+2.62(6)			(Bl64, Re66)
						+0.71(21)^{u}	(Bu63, Re66)
	91.0	5/2	1.375(3)^{a}	3.60(8)	0.8(4)	0.6(3)^{u}	Ba70, No71a
			1.371(3)^{a}	3.60(8)			Pa71a
			1.373(2)^{b}	3.60(5)^{b}			
^{147}Sm	0	7/2		-0.813(1)			(Wo66)
						-0.18(3)^{u}	(Ro69)
	122.1	5/2	+0.551(31)^{c,d}	-0.448(25)^{c}	+1.7(7)^{c,d}	-0.31(12)^{c,u}	Pa70a, Pa71
^{149}Sm	0	7/2		-0.670(6)		+0.058(6)^{u}	(Wo66)

Table 1. Nuclear moment data from Mössbauer spectroscopy--continued.

Isotope	Energy	Spin	R_μ	μ	R_Q	Q	Reference
^{149}Sm	0	7/2				< 0.06[f,u]	No67a
						0.060(15)[c,f,g,u]	Ei71
	22.5	5/2	+ 0.82[d]	-0.55			Gr64
			+ 0.93 (1)	- 0.623 (9)		0.40 (6)[g,u]	Of65b,No67a,Of67
			+ 0.929 (1)[c]	- 0.623 (6)[c]	8.3(21)[d,c]	0.50 (1)[g,c,u]	Ei71
^{152}Sm	121.8	2		0.84 (5)[g]			At67
^{154}Sm	81.9	2		0.78 (4)[g]		- 1.3 (5)	Wh69
^{151}Eu	0	5/2		+ 3.4649 (23)			(Ev65, Ki70)
						+ 1.14 (5)[g,u]	(Mu65,Wi65,Gu68)
	21.6	7/2	+ 0.739 (7)	+ 2.561 (24)			Ba63
			0.74 (4)	2.57 (15)	1.3 (5)	1.5 (6)[u]	No63a
			0.74 (4)	2.57 (15)			Co64
			+0.742 (1)	+ 2.571 (5)			Ki64
					1.64 (7)	1.87 (11)[u]	No68
			0.7465 (6)[c]	2.5865 (26)[c]	+1.28 (4)[a]	+ 1.46 (8)[u]	St68,Cr69,St69, Cr72, Cr73a
					1.30 (5)[a]	1.48 (9)[u]	Ka69, Ka70
					1.30 (4)[a]	1.48 (8)[u]	Du70
					1.34 (3)[a]	1.53 (8)[u]	Ch72, Ch74a
					+ 1.312 (19)[b]	+1.50 (7)[b,u]	
^{153}Eu	0	5/2		+1.5294 (7)			(Ev65, Ki70)
						+ 2.90 (12)[u]	(Mu65, Wi65, Gu68)
	83.4	7/2	+ 1.18 (4)	+ 1.80 (6)			Ri69
	97.4	5/2	+ 2.10 (15)	+ 3.21 (23)			At66b
				2.50 (25)			De66a
	103.2	3/2	+ 1.33 (5)	+ 2.04 (7)			At64
				1.9 (2)			De66a
			+ 1.25 (4)	+ 1.91 (6)			Ri69
			1.336 (7)[a]	2.043 (11)	0.520 (3)	1.51 (6)[u]	Ar69, Ar73
			1.336 (4)[a]	2.043 (6)			Cr72, Cr73a
			+ 1.336 (3)[b]	2.043 (5)[b]			
^{155}Gd	0	3/2		- 0.2584 (5)		+1.59 (16)[u]	(Un69)

Table 1. Nuclear moment data from Mössbauer spectroscopy--continued.

Isotope	Energy	Spin	R_u	u	R_Q	Q	Reference
^{155}Gd	86.5	5/2	-3.5(5)	+0.90 (13)			De66
			+2.09 (20)^{d}	-0.54 (5)	0.20 (10)	0.31 (16)^{u}	Bl68, Bl68a
			+2.27 (7)	-0.587 (17)	0.346 (12)^{a}	0.54 (6)^{u}	To68
			+2.03 (2)	-0.525 (4)	0.12 (1)^{a}	0.187 (16)^{u}	Ba69a
					+2.17 (22)	+3.4 (5)^{u}	Ba69
					0.12 (2)^{a}	0.19 (4)^{u}	Ka72a
			2.058 (13)^{a}	0.532 (4)	0.087 (6)^{a}	0.136 (16)^{u}	Ar73, Ar74
			2.005 (28)^{a}	0.518 (7)	0.35 (6)^{a}	0.55 (9)^{u}	Bo74
			+2.049 (20)^{b}	-0.529 (5)^{b}	0.14 (5)^{b}	0.22 (8)^{b,u}	
	105.3	3/2	$\begin{bmatrix}-0.51\ (16)\\+1.50\ (6)\end{bmatrix}^{d,h}$	$\begin{bmatrix}+0.13\ (4)\\-0.39\ (6)\end{bmatrix}^{h}$	0.9 (1)^{a}	1.40 (21)^{a,u}	Bl68, Bl68a
			$\begin{bmatrix}-0.55\ (5)\\+2.01\ (5)\end{bmatrix}^{h}$	$\begin{bmatrix}+0.142\ (13)\\-0.519\ (13)\end{bmatrix}^{h}$	1.00 (3)^{a} 0.99 (3)^{b}	1.56 (26)^{a,u} 1.57 (16)^{b,u}	Ar73, Ar74
^{156}Gd	88.9	2		0.792 (14)^{g,a}			Pe68
					r6	1.21 (13)^{u}	St67
					r6	1.89 (23)^{u}	To68
			r8	+0.773 (8)^{a}	r6	-2.40 (24)^{c,u}	Ar74
				+0.788 (7)^{b}			
^{157}Gd	0	3/2		-0.3388 (7)			(Ba69b)
					r7	2.00 (26)^{f,u}	Pr68
	64.0	5/2			1.78 (4)^{a}	3.6 (5)^{u}	Pr68
			+1.515 (7)	-0.5133 (26)			Go72
					1.80 (3)^{a}	3.6 (5)^{u}	Ar74
					1.79 (2)^{b}	3.6 (5)^{b,u}	
^{158}Gd	79.5	2		0.77 (4)^{g}			Fi67
					r9	1.30 (14)^{u}	St67
^{160}Gd	75.3	2			r10	1.34 (14)^{u}	St67
^{159}Tb	0	3/2		+2.008 (4)			(Ba65)
	58.0	5/2	$\begin{bmatrix}0.80\ (5)\\1.15\ (5)\end{bmatrix}^{h}$	$\begin{bmatrix}+1.60\ (10)\\+2.29\ (10)\end{bmatrix}$			At66a
^{160}Dy	86.8	2	r11	0.96 (8)			Co64
				0.74 (8)^{a,g}			Co65
			r11	0.78 (5)^{a}			Of65
				0.77 (4)^{b}			

Table 1. Nuclear moment data from Mössbauer spectroscopy--continued.

Isotope	Energy	Spin	R_μ	μ	R_Q	Q	Reference
^{161}Dy	0	5/2		-0.479(5)			(Fe74)
						+2.35(16)	(El57, Eb67)
	25.6	5/2	-1.14(27)^{d}	+0.54(13)			Ba61
					1.30	3.06^{e}	St63a
			-1.2(1)	+0.57(5)	1.20(5)	2.82(23)	Ba64, Ba64a
			-1.21(2)	+0.580(11)	0.98(3)	2.30(16)	No65
			-1.2(1)	+0.57(5)	0.85(10)	2.00(14)	Lu66
			-1.18(3)	+0.565(16)	1.03(6)	2.42(22)	Of66
			-1.21(2)	+0.580(11)	+1.01(3)	+2.37(18)	Bo67
			1.22(3)	+0.584(15)	1.00(3)	2.35(17)	Cr68
			-1.241(4)^{a}	+0.594(6)	0.95(10)	2.2(3)	Of65a, Kh70
			-1.243(10)^{a}	+0.595(8)	+1.007(10)	+2.37(16)	Be71
			-1.236(2)^{a}	+0.592(6)	0.9995(2)^{a}	2.35(16)	Co71
			-1.233(6)^{a}	+0.591(7)	0.995(9)	2.34(16)	Go71a
			1.241(4)^{a}	0.594(6)			No71a
			1.2365(10)^{a}	0.592(6)	1.0015(10)^{a}	2.35(16)	Bo74a
			-1.2368(8)^{b}	+0.592(6)^{b}	+0.9996(4)^{b}	+2.34(16)^{b}	
	43.8	7/2	+0.293(10)	-0.140(5)	0.21(5)	0.49(12)	Sy71, Sy73
	74.6	3/2	3.5	≈1.7			Sk61
			+0.84(5)	-0.402(24)	+0.48(4)	+1.13(12)	Bo67
			+0.852(12)^{a}	-0.408(7)	+0.60(5)^{a}	+1.41(15)	He67, He68
			+0.840(24)^{a}	-0.402(12)	+0.56(4)^{a}	+1.32(13)	Cr68
			+0.828(15)^{a}	-0.396(7)	0.58(4)^{a}	1.36(10)	Kh68
			+0.840(7)^{b}	-0.403(6)^{b}	+0.577(25)^{b}	+1.36(11)^{b}	
^{162}Dy	80.7	2		+0.74(8)^{g}			He67a, He68
^{164}Dy	73.4	2	r 12	+0.68(3)^{a}	r 13	-1.95(21)	Mu66a, Mu68
				+0.71(5)^{a,g}			Ol68
				0.69(3)^{b}			
^{165}Ho	0	7/2		+4.12(4)			(Ha72)
	94.7	9/2	0.99(4)	4.08(16)			Ge72
^{164}Er	91.5	2	r 14	0.694(15)			Mu68
^{166}Er	80.6	2		~ 0.5^{g}			Ki62

Table 1. Nuclear moment data from Mössbauer spectroscopy--continued.

Isotope	Energy	Spin	R_μ	μ	R_Q	Q	Reference
^{166}Er	80.6	2		$\pm 0.61\,(3)^{a,g}$		$-1.60\,(16)^{a,g,u}$	Co64b
			r 15	$0.624\,(15)^{a}$			Do64
						$-1.5\,(5)^{a,g,u}$	Hu65a
				$0.640\,(16)^{a,g}$			Mu68
				$0.629\,(10)^{b}$		$-1.59\,(15)^{b,u}$	
^{168}Er	79.8	2		$0.66\,(4)^{a,g}$			St67
			r 16	$0.655\,(14)^{a}$			Mu66b, Mu68
				$0.656\,(13)^{b}$			
^{170}Er	79.3	2	r 17	0.630 (13)	r 18	$1.67\,(30)^{u}$	Wi68a, Wi69
^{169}Tm	0	1/2		-0.2310 (15)			(Gi67)
	8.4	3/2				$-1.1\,(1)^{a,g}$	Hu63
			$-2.33\,(4)^{a}$	+ 0.538 (10)		$-1.09\,(5)^{g,u}$	Ka63
			-3.2 (7)	+0.75 (15)			No63
			$-2.17\,(10)^{a}$	+ 0.501 (23)		$-1.3\,(1)^{a,g}$	Co64a
			$-2.40\,(7)^{a,d}$	+0.554 (17)		$-1.5^{a,g}$	Ki64
			$-2.22\,(7)^{a}$	+ 0.513 (16)			Co68
			$-2.31\,(4)^{b}$	$+0.534\,(10)^{b}$		$-1.21\,(8)^{b}$	
^{170}Yb	84.3	2				-2.14^{u}	(El60)
				$0.668\,(10)^{a,g}$			Hu65
				$0.66\,(4)^{a,g}$			Ec67a
				$0.670\,(12)^{a,g}$			Mu68
				$0.669\,(8)^{b}$			
^{171}Yb	0	1/2		+0.49188 (20)			(Cl72)
	66.7	3/2			r 19	$-1.56^{a,u}$	Ka65
			$0.716\,(6)^{a,d}$	0.3520 (3)	r 19	$-1.61^{a,u}$	Gu66
			$0.706\,(5)^{a}$	0.3475 (22)			He66
					r 19	$-1.61^{a,u}$	Pl71
			$0.710\,(5)^{b}$	$0.349\,(2)^{b}$		$-1.59\,(3)^{b,u}$	
	75.9	5/2			r 20	$-2.24^{a,u}$	Ka66
			2.055 (10)	1.011 (5)			He67, He70
					r21	$-2.18^{a,u}$	Pl71
						$-2.21\,(4)^{b,u}$	

Table 1. Nuclear moment data from Mössbauer spectroscopy--continued.

Isotope	Energy	Spin	R_{μ}	μ	R_Q	Q	Reference
^{172}Yb	78.7	2		0.670 (20)^{g}			Mu66
					r22	-2.16^{a,u}	Ec67
			r23	0.663 (13)			Mu68
				0.664 (8)^{c}			Mu68
					r22	-2.18^{a,u}	Pl71
						-2.17 (4)^{b,u}	
^{174}Yb	76.5	2			r24	-2.22^{u}	Ec67c, Ec67
				0.676 (30)^{a,g}			Ec67a
			r25	0.673 (12)			Mu66 Mu66c
				0.670 (6)^{a,g}			Mu68
				0.676 (8)^{a,g}	r24	-2.14^{a,u}	He71
					r24	-2.14^{a,u}	Pl71
				0.672 (5)^{b}		-2.14 (4)^{b,u}	
^{176}Yb	82.1	2	1	0.76 (4)^{g}	r26	-2.24^{u}	Ec67
							Ec67b, Ec67a
^{176}Hf	88.4	2				-2.08^{u}	(Ha61)
^{178}Hf	93.2	2			r27	-1.89^{a,u}	Ge68
					r27	-2.00^{a,u}	Sn68
						-1.94 (6)^{b,u}	
^{180}Hf	93.3	2			r28	-2.02^{a,u}	Ge66, Ge68
					r28	-1.98^{a,u}	Sn68
					r29	-1.91^{a,u}	Sn68
					r28	-1.98^{a,u}	Ch70
					r29	-1.88^{a,u}	Ch70
					r29	-1.85^{a,u}	Bo73
					r29	-1.84^{a,u}	Zi73
			r30				Ko71
						-1.92 (2)^{b,u}	
^{181}Ta	0	7/2		+2.35 (1)			(Er73)
						+3.9 (4)^{u}	(Mu57)
	6.2	9/2	+2.19 (6)^{a}	+5.16 (15)	+0.74 (30)	+2.9 (3)^{u}	Sa68
			+2.25 (4)^{a}	+5.29 (10)			Ka70a

Table 1. Nuclear moment data from Mössbauer spectroscopy--continued.

Isotope	Energy	Spin	R_μ	μ	R_Q	Q	Reference
^{181}Ta	6.2	9/2			+1.133 (10)^{c}	+ 4.4 (5)^{c,u}	Sa72,Ka72,Ka73
			+2.23 (3)^{b}	+5.24 (7)^{b}			
^{180}W	103.0	2			r31	- 1.87^{a,u}	He72
					r31	- 1.78^{a,u}	Zi73
						- 1.82 (4)^{b,u}	
^{182}W	100.1	2				- 1.81^{u}	(Ha61)
				0.47 (5)^{a,e}			Ch65
				0.532 (18)^{a,g}			Pe68b
				0.44 (4)^{a,g}			Fr67, Fr69
				0.512 (25)^{b}			
^{183}W	46.5	3/2			r32	- 1.5	Sh66
				- 0.1 (1)^{g}			Ag67
	99.1	5/2	r33	0.90 (5)^{a}	r34	- 1.70^{a,u}	Ag67
				0.930 (43)^{a,g}			Pe68a
					r34	- 1.56^{a,u}	Ge74
				0.92 (3)^{b}		- 1.63 (7)^{b,u}	
^{184}W	111.2	2			r35	> 1.36^{u}	Ph62
				0.50 (6)^{a,e}			Ch65
				0.59 (2)^{a,g}	r35	- 1.70^{a,u}	Pe67, Pe68a, Pe68b
					r35	- 1.68^{a,u}	Ch69a
					r35	- 1.75^{a,u}	Ob71
					r35	- 1.73^{a,u}	Ge74
			r36	0.57 (3)^{a}			Pe68a, Pe68b
				0.578 (17)^{b}		- 1.72 (3)^{b,u}	
^{186}W	122.5	2		0.68 (6)^{a,e}			Ch65
			r37	0.60 (3)^{a}			Pe67, Pe68a Pe68b
				0.624 (22)^{a,g}	r38	- 1.60^{a,u}	Pe67, Pe68a Pe68b
					r38	- 1.64^{a,u}	Ch69a
					r38	- 1.64^{a,u}	Ob71
						- 1.73^{a,u}	Ge74
				0.621 (17)^{b}		- 1.65 (3)^{b,u}	

Table 1. Nuclear moment data from Mössbauer spectroscopy--continued.

Isotope	Energy	Spin	R_μ	μ	R_Q	Q	Reference
^{186}Os	137.2	2		0.64 (3) ^{a,e}			Ch65
				0.562 (16) ^{a,g}		-1.50 (10) ^{u}	Wa70, Wa72
				0.58 (3) ^{b}			
^{188}Os	155.0	2		0.62 (5) ^{a,e}			Ch65
			r39	0.63 (4) ^{a}	r40	-1.36 (9) ^{u}	Wa70, Wa72
				0.63 (3) ^{b}			
^{189}Os	0	3/2		+ 0.6565 (3)			(Sc68)
						0.8 (2) ^{u}	(Mu57)
					r41	0.94 (7) ^{f,u}	Wa72
	36.3	1/2	0.34 (4)	0.23 (3)			Wa69
	69.6	5/2	1.508 (15) ^{a}	0.990 (10)			Pe68c
			1.47 (3)	0.965 (20)			Gr69a
			1.488 (22) ^{a}	0.977 (14)	- 0.735 (12)	- 0.6 (2) ^{u}	Ku68, Wa72
			1.502 (12) ^{b}	0.986 (8) ^{b}			
^{190}Os	187.0	2			r42	- 1.17 (11) ^{u}	Wa72
^{191}Ir	0	3/2		+ 0.1453 (6)			(Na68)
						+ 0.78 (20) ^{u}	(Bu73)
	82.4	1/2	+3.71 (3) ^{c}	+0.540 (5) ^{c}			Wa67a, Wa68
			+3.55 (17) ^{d}	+0.515 (25)			Ow69
	129.5	5/2		3.00 (58) ^{e}			Da68
			+3.8 (8) ^{d,c}	+ 0.55 (5) ^{c}			Ow69
^{193}Ir	0	3/2		+ 0.1583 (6)			(Na68)
						+ 0.70 (18) ^{u}	(Bu73)
	73.1	1/2	3.0 (1)	0.47			At67a
			2.958 (6) ^{c}	0.4683 (20) ^{c}			Wa67, Wa67a Wa68
			3.015 (13)	0.4772 (27)			Pe69
^{195}Pt	0	1/2		+ 0.6060 (3)			(Pr51)
	98.8	3/2		- 0.8 (1)			Be65
				- 0.65 (15)			At66
			- 1.01 (8) ^{c,d}	- 0.61 (5) ^{c}			Ag67a
				- 0.60 (15)			Bu67

Table 1. Nuclear moment data from Mössbauer spectroscopy--continued.

Isotope	Energy	Spin	R_μ	μ	R_Q	Q	Reference
^{195}Pt	129.8	5/2	1.35(30)[a]	0.82(2)[a]			Wa71
				0.88(11)[a,g]			Wo72
				0.90(8)[a,g]			Ru71, Ru74
				0.854(19)[b]			
^{197}Au	0	3/2		+ 0.1448(7)			(Da67)
	77.3	1/2		+ 0.37(4)			Gr64b
			2.89(3)[a,d]	0.419(5)			Co68a
			2.864(28)[a,d]	0.415(4)			Ro63, Se65, Pa67a Bu68, Th68, Pa70
			2.875(22)[b]	0.416(3)[b]			
^{234}U	43.5	2				-2.89(4)[u]	(Fo71)
^{236}U	45.2	2			r44	-2.86(15)[a,u]	Mo72, Mo74
			r45		r44	-3.27(26)[a,u]	Me72, Me74
						-2.96(18)[b,u]	
^{238}U	44.9	2				-3.0	Ru69
					r46	-3.21(21)[a,u]	Mo72, Mo74
			r47		r46	-3.27(29)[a,u]	Me72, Me74
						-3.23(17)[b,u]	
^{237}Np	0	5/2		+2.5(3)			(Hu60, Ei65, Le70)
						+ 4.1(7)[f]	Du69
	59.5	5/2	+0.537(5)[a]	+1.34(12)	+ 0.99(1)[c]	+ 4.1(7)[c,u]	St68a, Pi68
			+0.533(5)[b]	+1.33(12)	+1.0(1)	+ 4.1[u]	Du68a, Du68
			+0.535(4)[b]	+1.34(12)[b]			
^{243}Am	0	5/2				+ 4.9[u]	(Ma56)
	84.0	5/2			+ 0.962(15)	+ 4.7[u]	Me73

[a] Value selected to be included in averaging procedure.

[b] Average of selected values, used as adopted value for the ratio or moment.

[c] Value selected as adopted value.

[d] Moment ratio calculated from the excited state and the ground state moments or appropriate splittings quoted in the reference.

[e] Obtained from a measurement of the angular distribution of resonant scattering.

[f] Ground state moment determined by Mössbauer spectroscopy.

[g] Moment derived assuming a known magnetic hyperfine field or electric field gradient which was obtained from other measurements or by calculation.

[h] Data inadequate to decide between two possibilities.

[u] Uncorrected for the Sternheimer effect.

Explanation of Table 2

Number

The number cross-references an entry in table 1. There the ratio value is combined with an adopted value for one of the moments to calculate the other moment.

Ratio

Moments are specified by the isotope and energy of the level in question. Thus $Q(^{57}\mathrm{Fe}, 14.4)$ is the quadrupole moment of the 14.4 keV level in ^{57}Fe.

Explanation of Table 3

Values for ratios and moments obtained either by direct selection or averaging are summarized from table 1. Notations and conventions are the same as in table 1. A listed R_μ or R_Q indicates the ratio of the moment for the indicated state to that of the ground state of the same isotope. Only results determined by Mössbauer spectroscopy are listed. Quadrupole moments marked with superscripts are uncorrected for Sternheimer corrections.

Table 2. Miscellaneous nuclear moment ratios from Mössbauer spectroscopy

Number	Ratio	Value	Reference
r 1	Q(^{99}Ru, 89.4)/Q(^{57}Fe, 14.4)	1.70(4)	Ba72a
r 2	Q(^{119}Sn, 23.83)/Q(^{121}Sb, 0)	0.22(7)	Mi72
r 3	Q(^{119}Sn, 89.5)/Q(^{119}Sn, 23.8)	2.2(2)	Be72
r 4	Q(^{125}Te, 35.5)/Q(^{127}I, 0)	0.30	Pa67
r 5	Q(^{129}Xe, 39.58)/Q(^{131}Xe, 0)	3.45(9)	Pe64
r 6	Q(^{156}Gd, 88.98)/Q(^{155}Gd, 0)	0.76(3)	St67
		1.19(8)	To68
		-1.51(2)	Ar74
r 7	Q(^{155}Gd, 0)/Q(^{157}Gd, 0)	0.78(6)	Pr68
r 8	μ(^{156}Gd, 87.5)/μ(^{155}Gd, 0)	-2.99(3)	Ar74
r 9	Q(^{158}Gd, 79.51)/Q(^{155}Gd, 0)	0.82(2)	St67
r 10	Q(^{160}Gd, 75.3)/Q(^{155}Gd, 0)	0.84(2)	St67
r 11	μ(^{160}Dy, 86.79)/μ(^{161}Dy, 0)	2.0(2)	Co64
		1.62(10)	Of65
r 12	μ(^{164}Dy, 73.39)/μ(^{161}Dy, 0)	-1.42(6)	Mu66a, Mu68
r 13	Q(^{164}Dy, 73.39)/Q(^{161}Dy, 0)	-0.83(7)	Mu66a, Mu68
r 14	μ(^{164}Er, 91.5)/μ(^{166}Er, 80.56)	1.103(15)	Mu67, Mu68
r 15	μ(^{166}Er, 80.56)/μ(^{167}Er, 0)	1.94(5)	Do64
r 16	μ(^{166}Er, 80.6)/μ(^{168}Er, 79.8)	0.960(13)	Mu68
r 17	μ(^{170}Er, 79.3)/μ(^{166}Er, 80.56)	1.002(13)	Wi68a, Wi69
r 18	Q(^{170}Er, 79.3)/Q(^{166}Er, 80.56)	1.05(16)	Wi68a, Wi69
r 19	Q(^{171}Yb, 66.74)/Q(^{170}Yb, 84.26)	0.73	Ka65
		0.75	Gu66
		0.752(16)	Pl71
r 20	Q(^{171}Yb, 75.89)/Q(^{171}Yb, 66.74)	1.41(5)	Ka66
r 21	Q(^{171}Yb, 75.89)/Q(^{170}Yb, 84.26)	1.020(27)	Pl71
r 22	Q(^{172}Yb, 78.67)/Q(^{170}Yb, 84.26)	1.01(2)	Ec67
		1.020(12)	Pl71
r 23	μ(^{172}Yb, 78.67)/μ(^{170}Yb, 84.26)	0.991(15)	Mu68

Table 2. Miscellaneous nuclear moment ratios from Mössbauer spectroscopy--continued.

Number	Ratio	Value	Reference
r24	$Q(^{174}\mathrm{Yb}, 76.5)/Q(^{170}\mathrm{Yb}, 84.26)$	1.04 (2)	Ec67c, Ec67
		1.001 (21)	He71
		1.000 (19)	Pl71
r25	$\mu(^{170}\mathrm{Yb}, 84.26)/\mu(^{174}(\mathrm{Yb}, 76.5)$	0.994 (13)	Mu66c, Mu68
r26	$Q(^{176}\mathrm{Yb}, 82.1)/Q^{170}(\mathrm{Yb}, 84.26)$	1.045 (20)	Ec67
r27	$Q(^{176}\mathrm{Hf}, 88.36)/Q^{178}(\mathrm{Hf}, 93.17)$	1.10 (2)	Ge68
		1.040 (8)	Sn68
r28	$Q(^{176}\mathrm{Hf}, 88.36)/Q(^{180}(\mathrm{Hf}, 93.33)$	1.03 (2)	Ge66, Ge68
		1.053 (15)	Sn68
		1.05 (2)	Ch70
r29	$Q(^{178}\mathrm{Hf}, 93.17)/Q(^{180}(\mathrm{Hf}, 93.33)$	1.014 (13)	Sn68
		1.03 (2)	Ch70
		1.05 (3)	Bo73
		1.052 (21)	Zi73
r30	$\mu(^{180}\mathrm{Hf}, 93.33)/\mu(^{178}\mathrm{Hf}, 93.17)$	0.96 (2)	Ko71
r31	$Q(^{180}\mathrm{W}, 103)/Q(^{182}\mathrm{W}, 100.1)$	1.03 (4)	He72
		0.983 (22)	Zi73
r32	$Q(^{183}\mathrm{W}, 46.48)/Q(^{182}\mathrm{W}, 100.1)$	0.83 (14)	Sh66
r33	$\mu(^{183}\mathrm{W}, 99.1)/\mu(^{182}\mathrm{W}, 100.1)$	1.75 (5)	Ag67
r34	$Q(^{183}\mathrm{W}, 99.1)/Q(^{182}\mathrm{W}, 100.1)$	0.94 (4)	Ag67
		0.86 (6)	Ge73
r35	$Q(^{184}\mathrm{W}, 111.2)/Q(^{182}\mathrm{W}, 100.1)$	$>$ 0.75	Ph62
		0.938 (15)	Pe67, Pe68a, Pe68b
		0.930 (16)	Ch69a
		0.965 (8)	Ob71
		0.955 (3)	Ge73
r36	$\mu(^{184}\mathrm{W}, 111.2)/\mu(^{182}\mathrm{W}, 100.1)$	1.11 (2)	Pe68a, Pe68b
r37	$\mu(^{186}\mathrm{W}, 122.5)/\mu(^{182}\mathrm{W}, 100.1)$	1.18 (3)	Pe67, Pe68a, Pe68b
r38	$Q(^{186}\mathrm{W}, 122.5)/Q(^{182}\mathrm{W}, 100.1)$	0.882 (17)	Pe67, Pe68a, Pe68b
		0.908 (24)	Ch69a
		0.906 (18)	Ob71
r39	$\mu(^{188}\mathrm{Os}, 155.03)/(\mu(^{186}\mathrm{Os}, 137.16)$	1.08 (5)	Wa70

Table 2. Miscellaneous nuclear moment ratios from Mössbauer spectroscopy--continued.

Number	Ratio	Value	Reference
r40	$Q(^{188}\mathrm{Os}, 155.03)/Q(^{186}\mathrm{Os}, 137.16)$	+ 0.909 (17)	Wa70, Wa72
r41	$Q(^{189}\mathrm{Os}, 0)/Q(^{188}\mathrm{Os}, 155.03)$	-0.586 (11)	Wa72
r42	$Q(^{190}\mathrm{Os}, 187)/Q(^{188}\mathrm{Os}, 155.03)$	+ 0.863 (51)	Wa72
r43	$Q(^{191}\mathrm{Ir}, 0)/Q(^{193}\mathrm{Ir}, 0)$	1.03 (3)	Wa67, Wa68a
r44	$Q(^{236}\mathrm{U}, 43.5)/Q(^{234}\mathrm{U}, 45.3)$	0.99 (5)	Mo72, Mo74
		1.13 (9)	Me72, Me74
r45	$\mu(^{236}\mathrm{U}, 43.5)/\mu(^{234}\mathrm{U}, 45.3)$	0.98 (6)	Me72, Me74
r46	$Q(^{238}\mathrm{U}, 44.7)/Q(^{234}\mathrm{U}, 45.3)$	1.11 (7)	Mo72, Mo74
		1.13 (10)	Me72, Me74
r47	$\mu(^{238}\mathrm{U}, 44.7)/\mu(^{234}\mathrm{U}, 45.3)$	0.94 (9)	Me72, Me74

Table 3. Summary of adopted values

Isotope	Energy	Spin	R_{μ}	μ	R_Q	Q
^{57}Fe	14.4	3/2	- 1.7142 (4)	- 0.15532 (4)		+ 0.209 (5)
^{61}Ni	67.4	5/2	- 0.637 (11)	+ 0.478 (7)	- 1.21 (13)	- 0.20 (3)
^{67}Zn	93.3	1/2	+ 0.66 (3)	+ 0.58 (3)		
^{83}Kr	9.4	7/2	+ 0.971 (2)	- 0.943 (2)	1.70 (2)	+ 0.430 (3)^{U}
^{99}Ru	89.3	3/2	0.456 (2)	- 0.285 (5)	+ 2.88 (4)	0.3 (7)^{U}
^{99}Tc	140.5	7/2	+ 0.64 (16)	+ 3.6 (8)		
^{119}Sn	23.8	3/2	- 0.605 (17)	+ 0.633 (18)		- 0.065 (5)^{U}
	89.0	11/2		1.40 (8)		- 0.14 (1)^{U}
^{121}Sb	0	5/2				- 0.28 (6)^{U}
	37.2	7/2	0.735 (9)	+2.47 (3)	1.34 (1)	- 0.38 (8)^{U}
^{125}Te	35.5	3/2	- 0.69 (6)	+ 0.61 (5)		- 0.200 (23)^{U}
^{127}I	57.6	7/2	0.905 (16)	2.54 (4)	- 0.896 (2)	- 0.71 (9)^{U}
^{129}I	27.8	5/2	1.0687 (11)	+ 2.797 (3)	+ 1.2380 (15)	- 0 68 (6)^{U}
^{129}Xe	39.6	3/2	- 0.75 (12)	+ 0.58 (9)		- 0.41 (4)
^{133}Cs	81.0	5/2	+ 1.335 (8)	+3.443 (21)		
^{141}Pr	145.2	7/2	+ 0.69 (2)	+ 2.87 (9)		
^{145}Nd	72.5	5/2	+ 0.489 (4)	- 0.320 (3)		
^{147}Pm	91.0	5/2	1.373 (2)	3.60 (5)	0.8 (4)	0.6 (3)^{U}
^{147}Sm	122.1	5/2	+ 0.551 (31)	- 0.448 (25)	+ 1.7 (7)	- 0.31 (12)^{U}
^{149}Sm	0	7/2				0.060 (15)^{U}
	22.5	5/2	+ 0.929 (1)	- 0.623 (6)	8.3 (21)	0.50 (1)^{U}
^{152}Sm	121.8	2		0.84 (5)		
^{154}Sm	81.9	2		0.78 (4)		- 1.3 (5)
^{151}Eu	21.6	7/2	0.7465 (6)	2.5865 (26)	1.312 (19)	+ 1.50 (7)^{U}
^{153}Eu	83.4	7/2	+ 1.18 (4)	+ 1.80 (6)		
	97.4	5/2	+ 2.10 (15)	+ 3.21 (23)		
	103.2	3/2	+ 1.336 (3)	2.043 (5)	0.520 (3)	1.51 (6)^{U}
^{155}Gd	86.5	5/2	+ 2.049 (20)	- 0.529 (5)	0.14 (5)	0.22 (8)^{U}
	105.3	3/2	- 0.55 (5) or + 1.80 (18)	+ 0.14 (4) or - 0.47 (7)	0.90 (3)	1.57 (16)^{U}
^{156}Gd	88.9	2		0.778 (7)		- 2.40 (24)

Table 3. Summary of adopted values--continued.

Isotope	Energy	Spin	R_μ	μ	R_Q	Q
^{157}Gd	0	3/2				2.00(26)^{u}
	64.0	5/2	+1.515(7)	0.5133(26)	1.79(2)	3.6(5)^{u}
^{158}Gd	79.5	2		0.77(4)		1.30(14)
^{160}Gd	75.3	2				1.34(14)
^{159}Tb	58.0	5/2	0.80(5) or	+1.60(10) or		
			1.15(5)	+2.29(10)		
^{160}Dy	86.8	2		0.77(4)		
^{161}Dy	25.6	5/2	-1.2368(18)	+0.592(6)	+0.9996(4)	+2.34(16)
	43.8	7/2	+0.293(10)	-0.140(5)	0.21(5)	0.49(12)
	74.6	3/2	+0.840(7)	-0.403(6)	+0.59(3)	+1.36(11)
^{162}Dy	80.7	2		+0.74(8)		
^{164}Dy	73.4	2		0.69(3)		-1.95(21)
^{165}Ho	94.7	9/2	0.99(4)	4.08(16)		
^{164}Er	91.5	2		0.694(15)		
^{166}Er	80.6	2		0.629(10)		-1.59(15)^{u}
^{168}Er	79.8	2		0.656(13)		
^{170}Er	79.3	2		0.630(13)		-1.67(30)^{u}
^{169}Tm	8.4	3/2	-2.31(4)	+0.534(10)		-1.21(8)
^{170}Yb	84.3	2		0.669(8)		
^{171}Yb	66.7	3/2	0.710(5)	0.349(2)		-1.59(3)^{u}
	75.9	5/2	2.055(10)	1.011(5)		-2.21(4)^{u}
^{172}Yb	78.7	2		0.664(8)		-2.17(4)^{u}
^{174}Yb	76.5	2		0.672(5)		-2.14(4)^{u}
^{176}Yb	82.1	2		0.76(4)		-2.24^{u}
^{176}Hf	88.4	2				-2.08^{u}
^{178}Hf	93.2	2				-1.94(4)^{u}
^{180}Hf	93.3	2				-1.92(2)^{u}
^{181}Ta	6.2	9/2	+2.23(3)	+5.24(7)	+1.133(10)	+4.4(5)^{u}
^{180}W	103.0	2				-1.82(4)^{u}
^{182}W	100.1	2		0.512(25)		
^{183}W	46.5	3/2		-0.1(1)		-1.5
	99.1	5/2		0.92(3)		-1.63(7)^{u}

Table 3. Summary of adopted values--continued.

Isotope	Energy	Spin	R_{μ}	μ	R_Q	Q
^{184}W	111.2	2		0.58 (2)		-1.72 (3)[u]
^{186}W	122.5	2		0.62 (2)		-1.65 (3)[u]
^{186}Os	137.2	2		0.58 (3)		-1.50 (10)[u]
^{188}Os	155.0	2		0.63 (3)		-1.36 (9)[u]
^{189}Os	0	3/2				0.94 (7)[u]
	36.3	1/2	0.34 (4)	0.23 (3)		
	69.6	5/2	1.502 (12)	0.986 (8)	-0.735 (12)	-0.6 (2)[u]
^{190}Os	187.0	2				-1.17 (11)[u]
^{191}Ir	0	3/2				+0.78 (20)[u]
	82.4	1/2	+3.71 (3)	+0.540 (5)		
	129.5	5/2	+3.8 (3)	+0.55 (5)		
^{193}Ir	73.1	1/2	2.958 (6)	0.4683 (20)		
^{195}Pt	98.8	3/2	-1.01 (8)	-0.61 (5)		
	129.8	5/2	1.35 (30)	0.854 (19)		
^{197}Au	77.3	1/2	2.875 (22)	0.416 (3)		
^{236}U	45.2	2				-2.95 (14)[u]
^{238}U	44.9	2				-3.23 (17)[u]
^{237}Np	0	5/2				+4.1 (7)[u]
	59.5	5/2	+0.535 (4)	+1.34 (12)	0.99 (1)	+4.1 (7)[u]
^{243}Am	84.0	5/2			+0.962 (15)	+4.7[u]

[u] Uncorrected for the Sternheimer effect.

3. Acknowledgements

The assistance of Virginia E. Stevens, Sheila W. Hedges, and Paul T. Deason in the compilations, proof reading, and general preparation of the tables is greatly appreciated. The attempt to conform this paper and its tables to the larger one on all nuclear moments was made possible by continuous discussion and correspondence with Gladys Fuller, its author. We are thankful for her effort and time in our behalf.

4. References

[Ab61] A. Abragam and F. Boutron, C. R. H. Acad. Sci. **252**, 2404 (1961).

[Ag67] D. Agresti, E. Kankeleit, and B. Persson, Phys. Rev. **155**, 1342 (1967).

[Ag67a] D. Agresti, E. Kankeleit, and B. Persson, Phys. Rev. **155**, 1339 (1967).

[Ar68] J. O. Artman, A. H. Muir, Jr., and H. Wiederisch, Phys. Rev. **173**, 337 (1968).

[Ar69] H. Armon, E. R. Bauminger, J. Hess, A. Mustachi, and S. Ofer, Phys. Letters **28A**, 528 (1969).

[Ar72] H. Armon, E. R. Bauminger, and S. Ofer, Phys. Letters **43B**, 380 (1972).

[Ar73] H. Armon, E. R. Bauminger, A. Diamant, I. Nowik and S. Ofer, Phys. Letters **44A**, 279 (1973).

[Ar74] H. Armon, E. R. Bauminger, A. Diamant, I. Nowik, and S. Ofer, Nucl. Phys. **A233**, 385 (1974).

[At64] U. Atzmony, A. Mualem, and S. Ofer, Phys. Rev. **136**, B1237 (1964).

[At66] M. Atac, P. Debrunner, and H. Frauenfelder, Phys. Letters **21**, 699 (1966).

[At66a] U. Atzmony, E. R. Bauminger, and S. Ofer, Nucl. Phys. **89**, 433 (1966).

[At66b] U. Atzmony and S. Ofer, Phys. Rev. **145**, 915 (1966).

[At67] U. Atzmony, E. R. Bauminger, D. Froindlich, and S. Ofer, Phys. Letters **26B**, 81 (1967).

[At67a] U. Atzmony, E. R. Bauminger, D. Lebenbaum, A. Mustachi, S. Ofer, and J. H. Wernick, Phys. Rev. **163**, 314 (1967).

[Ba61] E. R. Bauminger, S. G. Cohen, A. Marinov, and S. Ofer, Phys. Rev. Letters **6**, 467 (1961).

[Ba63] P. H. Barrett and D. A. Shirley, Phys. Rev. **131**, 123 (1963).

[Ba64] E. Bauminger, L. Grodzins, and A. J. Freeman, in *Proceedings of the Third International Conference on the Mössbauer Effect* (Ed. A. J. Bearden), Rev. Mod. Phys. **36**, 392 (1964).

[Ba64a] E. R. Bauminger, L. Grodzins, and A. Freeman, Bull. Am. Phys. Soc. **9**, 451 (1964).

[Ba65] J. M. Baker, J. R. Chadwick, G. Garton, and J. P. Hurrell, Proc. Roy. Soc., London **286A**, 352 (1965).

[Ba69] A. E. Balabanov, N. N. Delyagin, E. N. Kornienko, and L. N. Pankratova, Yad. Fiz. **9**, 1116 (1969)/Sov. J. Nucl. Phys. **9**, 653 (1969).

[Ba69a] E. R. Bauminger, D. Froindlich, A. Mustachi, I. Nowik, S. Ofer, and S. Samuelov, Phys. Letters **30B**, 531 (1969).

[Ba69b] J. M. Baker, G. M. Copland, and B. M. Wanklyn, J. Phys. Soc. C (Solid State Phys.) **2**, 862 (1969).

[Ba70] E. R. Bauminger, D. Froindlich, A. Mustachi, S. Ofer, and M. Perkal, Phys. Letters **32B**, 678 (1970).

[Ba71] G. M. Bancroft, Chem. Phys. Letters **10**, 449 (1971).

[Ba72] E. R. Bauminger, J. Hess, I. Nowik, and S. Ofer, Solid State Commun. **10**, 365 (1972).

[Ba72a] G. M. Bancroft, K. D. Butler, and E. T. Libbey, J. Chem. Soc., Dalton Trans. 2643 (1972).

[Ba73] P. H. Barrett and H. Micklitz, in *Perspectives in Mössbauer Spectroscopy* (Ed. S. G. Cohen and M. Pasternak), Plenum Press, New York, 1973, p. 117.

[Ba74] G. M. Bancroft and K. D. Butler, J. Amer. Chem. Soc. **96**, 7208 (1974).

[Be60a] R. Bersohn, Phys. Rev. Letters **4**, 609 (1960).

[Be65] N. Benczer-Koller, J. R. Harris, and G. M. Rothberg, Phys. Rev. **140**, B547 (1965).

[Be65a] R. G. Bessent and W. Haynes, Proc. Roy. Soc., London **285A**, 430 (1965).

[Be71] M. Belakhovsky, J. Phys. (Paris), Collog. **32** Suppl., Cl–915 (1971).

[Be71a] M. F. Bent, D. D. Cook, and B. I. Persson, Phys. Rev. C **3**, 1419 (1971).

[Be72] G. N. Belozerskii, D. Gumprecht, and P. Steiner, Phys. Letters **42B**, 349 (1972).

[Bl68] H. Blumberg, B. Persson, and M. Bent, in *Hyperfine Structure and Nuclear Radiations* (Ed. E. Matthias and D. A. Shirley), North-Holland Publ. Co., Amsterdam, 1968, p. 252.

[Bl68a] H. Blumberg, B. Persson, and M. Bent, Phys. Rev. **170**, 1076 (1968).

[Bo61] A. J. F. Boyle, D. St. P. Bunbury, and C. Edwards, Proc. Phys. Soc., London **77**, 1062 (1961).

[Bo62] A. J. F. Boyle, D. St. P. Bunbury, and C. Edwards, Proc. Phys. Soc., London **79**, 416 (1962).

[Bo66] D. Bosch, F. Pobell, and P. Kienle, Phys. Letters **22**, 262 (1966).

[Bo67] G. J. Bowden, D. St. P. Bunbury, and J. M. Williams, Proc. Phys. Soc., London **91**, 612 (1967).

[Bo71] E. Both, G. Trumpy, and C. Djega-Mariadassou, Phys. Letters **35A**, 27 (1971).

[Bo71a] E. Both, G. Trumpy, and C. Djega-Mariadassou, in *Application of the Mössbauer Effect* (Ed. I. Dezsi), Akademia Kiado, Budapest, 1971, p. 375.

[Bo73] P. Boolchand, S. Jha, and H. Bakhru, in *Nuclear Moments and Nuclear Structure, Proceedings of International Conference, Osaka, 1972* (Ed. H. Horie and K. Sugimoto), Suppl. J. Phys. Soc. Jap. **34**, 576 (1973).

[Bo74] G. J. Bowden, J. W. Ross and K. A. McEwen, in *Magnetic Resonance and Related Phenomena, Proceedings of AMPERE Congress, 18th* (Ed. P. S. Allen, E. R. Andrew, and C. A. Bates), North-Holland Publ. Co. Amsterdam, 1974, p. 77.

[Bo74a] G. J. Bowden, R. K. Day, and M. Sarwar, in *Proceedings of the International Conference of Magnetism ICM–73 (Moscow, 1973)*, "Nauka," Moscow, 1974, p. 475.

[Br62] V. A. Bryukhanov, N. N. Delyagin, and V. S. Shpinel', Zh. Eksp. Teor. Fiz. **42**, 1183 (1962)/Sov. Phys.-JETP **15**, 818 (1962).

[Br68] D. Brinkman, Phys. Letters **27A**, 466 (1968).

[Br73] J. S. Brooks, J. M. Williams and P. J. Webster, J. Phys. D: Appl. Phys. **6**, 1403 (1973).

[Bu61] G. Burns, Phys. Rev. **124**, 524 (1961).

[Bu63] B. Budick and P. Marrus, Phys. Rev. **133**, 723 (1963).

[Bu67] A. Buyrn, L. Grodzins, N. A. Blum, and J. Wulff, Phys. Rev. **163**, 286 (1967).

[Bu68] J. W. Burton, L. D. Roberts, and J. O. Thomson, Bull. Am. Phys. Soc. **13**, 250 (1968).

[Bu73] S. Büttgenbach, M. Hershel, G. Meisel, E. Schrödl, W. White, and W. J. Childs, Z. Phys. **263**, 341 (1973).

[Ca68] L. E. Campbell, G. J. Perlow, and N. C. Sandstrom, in *Hyperfine Structure and Nuclear Radiations* (Ed. E. Matthias and D. A. Shirley), North-Holland Publ. Co., Amsterdam, 1968, p. 161.

[Ca68a] L. E. Campbell and G. J. Perlow, Nucl. Phys. **A 109**, 59 (1968).

[Ca69] L. E. Campbell, G. J. Perlow, and M. A. Grace, Phys. Rev. **178**, 1728 (1969).

[Ch63] J. Chappert and P. Imbert, J. Phys. (Paris) **24**, 412 (1963).

[Ch65] Y. W. Chow, L. Grodzins, and P. H. Barrett, Phys. Rev. Letters **15**, 369 (1965).

[Ch68] W. J. Childs and L. S. Goodman, Phys. Rev. **170**, 136 (1968).

[Ch69] J. Chappert, R. B. Frankel, A. Misetich, and N. A. Blum, Phys. Rev. **179**, 578 (1969).

[Ch69a] Y. W. Chow, E. S. Greenbaum, R. H. Howes, F. H. H. Hsu, P. H. Swerdlow, and C. S. Wu, Phys. Letters **30B**, 171 (1969).

[Ch69b] J. Chappert, R. B. Frankel, A. Misetich, and N. A. Blum, Phys. Letters **28B**, 406 (1969).

[Ch70] Y. W. Chow, R. H. Howes, P. H. Swerdlow, C. S. Yen, and C. S. Wu, Phys. Letters **32B**, 682 (1970).

[Ch72] C.-L. Chien and F. de S. Barros, Phys. Letters **38A**, 427 (1972).

[Ch74] B. M. Cheyne and C. H. W. Jones, Can. J. Chem. **52**, 564 (1974).

[Ch74a] C.-L. Chien, S. DeBenedetti, and F. de S. Barros, Phys. Rev. B **10**, 3913 (1974).

[Co50] V. W. Cohen, W. D. Knight, T. Wentink, Jr., W. S. Koski, Phys. Rev. **79**, 191 (1950).

[Co63] R. L. Cohen, P. G. McMullin, and G. K. Wertheim, Rev. Sci. Instrum. **34**, 671 (1963).

[Co64] S. G. Cohen, I. Nowik, and S. Ofer, in *Proceedings of the Third International Conference on the Mössbauer Effect* (Ed. A. J. Bearden), Rev. Mod. Phys. **36**, 378 (1964).

[Co64b] R. L. Cohen and J. H. Wernick, Phys. Rev. **134**, B503 (1964).

[Co64c] M. Cordey-Hayes, J. Inorg. Nucl. Chem. **26**, 915 (1964).

[Co65] R. L. Cohen, Phys. Rev. **137**, A1809 (1965).

[Co68] R. L. Cohen, Phys. Rev. **169**, 432 (1968).

[Co68a] R. L. Cohen, Phys. Rev. **171**, 343 (1968).

[Co71] R. L. Cohen and K. W. West, in *Hyperfine Interactions in Excited Nuclei* (Ed. G. Goldring and R. Kalish), Gordon and Breach Science Publishers Inc., New York, 1971, p. 613.

[Cr67] T. E. Cranshaw and P. Reivari, Proc. Phys. Soc., London **90**, 1059 (1967).

[Cr68] G. Crecelius and D. Quitmann, in *Hyperfine Structure and Nuclear Radiations* (Ed. E. Matthias and D. A. Shirley), North-Holland Publ. Co., Amsterdam, 1968, p. 172.

[Cr69] G. Crecelius and S. Hufner, Phys. Letters **30A**, 124 (1969).

[Cr72] G. Crecelius, Z. Phys. **256**, 155 (1972).

[Cr73] G. Crecelius, Z. Phys. **258**, 56 (1973).

[Cr73a] G. Crecelius, in Proceedings of the *International Conference on Nuclear Moments and Nuclear Structure* (Eds. H. Horie and K. Sugimoto), Suppl. J. Phys. Soc. Jap. **34**, 579 (1973).

[Da67] H. Dahmen and S. Penselin, Z. Phys. **200**, 456 (1967).

[Da68] A. V. Davydov, G. R. Kartashov, and Yu. V. Khrudev, Yad. Fiz. **7**, 735 (1968)/Sov. J. Nucl. Phys. **7**, 447 (1968).

[De60] N. N. Delyagin, V. S. Shpinel', V. A. Bryukhanov, and B. Zvenglinskii, Zh. Eksp. Teor. Fiz. **39**, 894 (1960)/Sov. Phys.-JETP **12**, 619 (1961).

[De61] S. DeBenedetti, G. Lang, and R. Ingalls, Phys. Rev. Letters **6**, 60 (1961).

[De63] H. de Waard, G. De Pasquali, and D. Hafemeister, Phys. Letters **5**, 217 (1963).

[De64] H. de Waard and J. Heberle, Phys. Rev. **136**, B1615 (1964).

[De66] N. Y. Delyagin, H. El Sayes, V. S. Shpinel', Zh. Eksp. Teor. Fiz. **51**, 95 (1966)/Sov. Phys.-JETP **24**, 64 (1967).

[De66a] P. Debrunner and H. Frauenfelder, in *Applications of the Mossbauer Effect in Chemistry and Solid State Physics*/ Acta Crystallogr. Suppl. **21**, Part 7, 58 (1966).

[De70] H. de Waard, S. R. Reintsema, and M. Pasternak, Phys. Letters **33B**, 413 (1970).

[De70a] J. Devooght, P. M. Gielen, and S. Lejeune, J. Organometal. Chem. **21**, 333 (1970).

[Do64] H. Dobler, G. Petrich, S. Hüfner, P. Kienle, W. Wiedemann, and H. Eicher, Phys. Letters **10**, 319 (1964).

[Dr64] L. E. Drain, Phys. Letters **11**, 114 (1964).

[Du68] B. D. Dunlap, G. M. Kalvius, S. L. Ruby, M. B. Brodsky, and D. Cohen, Phys. Rev. **171**, 316 (1968).

[Du68a] B. D. Dunlap, G. M. Kalvius, S. L. Ruby, M. B. Brodsky, and D. Cohen, in *Hyperfine Structure and Nuclear Radiations* (Ed. E. Matthias and D. A. Shirley), North-Holland Publ. Co., Amsterdam, 1968, p. 84.

[Du69] B. D. Dunlap and G. M. Kalvius, Phys. Rev. **186**, 1296 (1969).

[Du70] G. W. Dulaney and A. F. Clifford, in *Mössbauer Effect Methodology* **5**, (Ed. I. J. Gruverman), Plenum Press, New York, 1970, p. 65.

[Eb67] W. Ebenhöh, V. J. Ehlers, and J. Ferch, Z. Phys. **200**, 84 (1967).

[Ec67] J. S. Eck, Y. K. Lee, J. C. Walker, and R. R. Stevens, Jr., Phys. Rev. **156**, 246 (1967).

[Ec67a] J. S. Eck, Y. K. Lee, and J. C. Walker, Phys. Rev. **163**, 1295 (1967).

[Ec67b] J. S. Eck, Y. K. Lee, and J. C. Walker, Bull. Am. Phys. Soc. **12**, 596 (1967).

[Ec67c] J. Eck, Y. K. Lee, E. T. Ritter, R. R. Stevens, Jr., and J. C. Walker, Phys. Rev. Letters **17**, 120 (1967).

[Ei63] H. Eicher, Z. Phys. **171**, 582 (1963).

[Ei65] J. C. Eisenstein and M. H. L. Pryce, J. Res. Nat. Bur. Stand., Sect. A **69**, 217 (1965).

[Ei67] M. Eibschütz, S. Shtrikman, and D. Treves, Phys. Rev. **156**, 562 (1967).

[Ei71] M. Eibschütz, R. L. Cohen, and J. H. Wernick, in *Hyperfine Interactions in Excited Nuclei* (Ed. G. Goldring and R. Kalish), Gordon and Breach Science Publishers Inc., New York, 1971, p. 720.

[El57] B. Elbek, K. O. Nielsen, and M. C. Olesen, Phys. Rev. **108**, 406 (1957).

[El60] B. Elbek, M. C. Olesen, and O. Skilbreid, Nucl. Phys. **19**, 523 (1960).

[Er68] U. Erich and D. Quitmann, in *Hyperfine Structure and Nuclear Radiations* (Ed. E. Matthias and D. A. Shirley), North-Holland Publ. Co., Amsterdam, 1968, p. 130.

[Er69] U. Erich, Z. Phys. **227**, 25 (1969).

[Er69a] U. Erich, K. Frölich, P. Gütlich, and G. A. Webb, Inorg. Nucl. Chem. Letters **5**, 855 (1969).

[Er73] L. C. Erich, A. C. Gossard, and R. L. Hartless, J. Chem. Phys. **59**, 3911 (1973).

[Ev65] L. Evans, P. G. H. Sandars, and G. K. Woodgate, Proc. Roy. Soc., London **289A**, 114 (1965).

[Fa63] W. L. Faust and L. Y. Chow Chin, Phys. Rev. **129**, 1214 (1963).

[Fe74] J. Ferch, W. Dankwort, and H. Gebauer, Phys. Letters **49A**, 287 (1974).

[Fi67] J. Fink, Z. Phys. **207**, 225 (1967).

[Fo69] S. Foner, A. J. Freeman, N. A. Blum, R. B. Frankel, E. J. McNiff, Jr., and H. C. Praddaude, Phys. Rev. **181**, 863 (1969).

[Fo71] J. L. C. Ford, Jr., P. H. Stelson, C. E. Bemis, Jr., F. K. McGowan, R. L. Robinson, and W. T. Milner, Phys. Rev. Letters **27**, 1232 (1971).

[Fr63] A. J. Freeman and R. E. Watson, Phys. Rev. **131**, 2566 (1963).

[Fr65] R. B. Frankel, J. Huntzicker, E. Matthias, S. S. Rosenblum, D. A. Shirley, and N. J. Stone, Phys. Letters **15**, 163 (1965).

[Fr67] R. B. Frankel, Y. Chow, L. Grodzins, and J. Wulff, Bull. Am. Phys. Soc. **12**, 378 (1967).

[Fr68] R. B. Frankel, J. J. Huntzicker, D. A. Shirley, and N. J. Stone, Phys. Letters **26A**, 452 (1968).

[Fr69] R. B. Frankel, Y. Chow, L. Grodzins, and J. Wulff, Phys. Rev. **186**, 381 (1969).

[Fr70] J. M. Friedt, J. Inorg. Nucl. Chem. **32**, 431 (1970).

[Fr71] J. M. Friedt, in *Application of the Mössbauer Effect* (Ed. I. Dezsi), Akademia Kiado, Budapest, 1971, p. 121.

[Fu69] G. H. Fuller and V. W. Cohen, Nucl. Data Tables **A 5**, 433 (1969).

[Ga62] J. Gastebois, in *Proceedings of the Second International Conference on the Mössbauer Effect* (Ed. D. M. J. Compton and A. H. Schoen), John Wiley and Sons, Inc., New York, 1962, p. 160.

[Ge66] E. Gerdau, H. J. Korner, J. Lerch, and P. Steiner, Z. Naturforsch. A **21**, 941 (1966).

[Ge68] E. Gerdau, P. Steiner, and D. Steenken, in *Hyperfine Structure and Nuclear Radiations* (Ed. E. Matthias and D. A. Shirley), North-Holland Publ. Co., Amsterdam, 1968, p. 261.

[Ge72] E. Gerdau, W. Raeth, and H. Winkler, Z. Phys. **257**, 29 (1972).

[Ge73] A. Gedikli, H. Winkler, and E. Gerdau, Z. Phys. **267**, 61 (1974).

[Ge67] D. Giglberger and S. Penselin, Z. Phys. **199**, 244 (1967).

[Gi73] T. C. Gibb, R. Greatrex, N. N. Greenwood, D. C. Puxley, and K. G. Snowden, Chem. Phys. Letters **20**, 130 (1973).

[Gi73a] T. C. Gibb, R. Greatrex, N. N. Greenwood, and P. Kaspi, J. Chem. Soc., Dalton Trans. 1253 (1973).

[Gi74] T. C. Gibb, R. Greatrex, N. N. Greenwood, and R. H. Meinhold, Chem. Phys. Letters **29**, 379 (1974).

[Go65] V. I. Gol'danskii, V. A. Trukhtanov, M. N. Devisheva, and V. F. Belov, Zh. Eksp. Teor. Fiz., Pis'ma Red. **1**, 31 (1965)/JETP Letters **1**, 19 (1965).

[Go65a] V. I. Gol'danskii, V. A. Trukhtanov, M. N. Devisheva, and V. F. Belov, Phys. Letters **15**, 317 (1965).

[Go68] *Chemical Applications of Mossbauer Spectroscopy*, (Ed. V. I. Gol'danskii and R. H. Herber), Academic Press, New York, 1968.

[Go71] J. Goring, Z. Naturforsch A**26**, 1931 (1971).

[Go71a] V. D. Gorobchenko, I. I. Lukashevich, V. G. Stankevich, N. I. Filippov, V. I. Chukalin, and E. I. Yarembash, Fiz. Tverd Tela **13**, 1085 (1971)/Sov. Phys.-Solid State **13**, 901 (1971).

[Go72] J. Goring, Z. Phys. **251**, 185 (1972).

[Gr64] L. Grodzins and E. R. Bauminger, Bull. Am. Phys. Soc. **9**, 497 (1964).

[Gr64a] L. Grodzins and N. Blum, in *Proceedings of the Third International Conference on the Mössbauer Effect* (Ed. A. J. Bearden), Rev. Mod. Phys. **36**, 470 (1964).

[Gr64b] R. W. Grant, M. Kaplan, D. A. Keller, and D. A. Shirley, Phys. Rev. **133**, A1062 (1964).

[Gr69] M. Greenshpan, D. Treves, S. Bukshpan, and T. Sonnino, Phys. Rev. **178**, 1802 (1969).

[Gr69a] M. C. Gregory, B. L. Robinson, and S. Jha, Phys. Rev. **180**, 1158 (1969).

[Gr73] J. L. Groves, G. DePasquali, and P. G. Debrunner, Phys. Rev. **7**, 1974 (1973).

[Gu66] C. Gunther and E. Kankeleit, Phys. Letters **22**, 443 (1966).

[Gu68] G. Guthöhrlein, Z. Phys. **214**, 332 (1968).

[Gu72] D. F. Gumprecht, T. E. Katila, L. C. Moberg, and P. O. Lipas, Phys. Letters **40A**, 297 (1972).

[Ha60] S. S. Hanna, L. Meyer-Schutzmeister, R. S. Preston, and D. H. Vincent, Phys. Rev. **120**, 2211 (1960).

[Ha60a] S. S. Hanna, J. Heberle, C. Littlejohn, G. J. Perlow, R. S. Preston, and D. H. Vincent, Phys. Rev. Letters **4**, 177 (1960).

[Ha61] O. Hansen, M. C. Olesen, O. Skilbreid, and B. Elbek, Nucl. Phys. **25**, 634 (1961).

[Ha64] D. W. Hafemeister, G. DePasquali, and H. de Waard, Phys. Rev. **135**, B1089 (1964).

[Ha68] C. B. Harris, J. Chem. Phys. **49**, 1648 (1968).

[Ha72] R. A. Haberstroh, T. I. Morgan, S. Penselin, Z. Phys. **252**, 421 (1972).

[Ha73] D. Hanzel and A. Moljk, Fizika **5**, 145 (1973).

[He64] J. Heberle, M. Schulhof, and S. S. Hanna, in *Proceedings of the Third International Conference on the Mössbauer Effect* (Ed. A. J. Bearden), Rev. Mod. Phys. **36**, 407 (1964).

[He66] W. Henning, P. Kienle, E. Steichele, and F. Wagner, Phys. Letters **22**, 446 (1966).

[He67] W. Henning, P. Kienle, and H. J. Körner, Z. Phys. **199**, 207 (1967).

[He67a] W. Henning, D. Heunemann, W. Weber, P. Kienle, and H. J. Körner, Z. Phys. **207**, 505 (1967).

[He67b] N. Hershkowitz and J. C. Walker, Phys. Rev. **156**, 391 (1967).

[He68] W. Henning, D. Heunemann, W. Weber, P. Kienle, and H. J. Körner, in *Hyperfine Structure and Nuclear Radiations* (Ed. E. Matthias and D. A. Shirley), North-Holland Publ. Co., Amsterdam, 1968, p. 178.

[He70] W. Henning, G. M. Kalvius, and G. K. Shenoy, Phys. Rev. C **2**, 2414 (1970).

[He71] W. Henning, G. Bahre, and P. Kienle, Z. Phys. **241**, 138 (1971).

[He72] N. Hershkowitz, S. A. Wender, and A. B. Carpenter, Phys. Rev. C **5**, 219 (1972).

[Hu60] C. A. Hutchinson and B. Weinstock, J. Chem. Phys. **32**, 56 (1960).

[Hu63] S. Hüfner, M. Kalvius, P. Kienle, W. Wiedemann, and H. Eicher, Z. Phys. **175**, 416 (1963).

[Hu64] J. J. Huntzicker, R. B. Frankel, N. J. Stone, and D. A. Shirley, Bull. Am. Phys. Soc. **9**, 741 (1964).

[Hu65] A. Huller, W. Wiedemann, P. Kienle, and S. Hüfner, Phys. Letters **15**, 269 (1965).

[Hu65a] S. Hüfner, P. Kienle, W. Wiedemann, and H. Eicher, Z. Phys. **182**, 499 (1965).

[In64] R. Ingalls, Phys. Rev. **133**, A787 (1964).

[In69] R. Ingalls, Phys. Rev. **188**, 1045 (1969).

[Ir70] S. M. Irkaev, Kh. Kh. Valiev, V. A. Golovnin, and R. N. Kuz'min, Dokl. Akad. Nauk. Tadzh. SSR **13(6)**, 16 (1970).

[Ir70a] S. M. Irkaev, Kh. Kh. Valiev, V. A. Golovnin, and R. N. Kuz'min, Zh. Eksp. Teor. Fiz. **59**, 419 (1970)/Sov. Phys.-JETP **32**, 229 (1971).

[Ja67] A. P. Jain and T. E. Cranshaw, Phys. Letters **25A**, 421 (1967).

[Jo67] C. E. Johnson, Proc. Phys. Soc., London **92**, 748 (1967).

[Jo68] C. E. Johnson, in *Hyperfine Structure and Nuclear Radiations* (Ed. E. Matthias and D. A. Shirley), North-Holland Publ. Co., Amsterdam, 1968, p. 226.

[Ka62] M. Kalvius, U. Zahn, P. Kienle, and H. Eicher, Z. Naturforsch, A **17**, 494 (1962).

[Ka63] M. Kalvius, P. Kienle, H. Eicher, W. Wiedemann, and C. Schuler, Z. Phys. **172**, 231 (1963).

[Ka65] G. M. Kalvius, Phys. Rev. **137**, B1441 (1965).

[Ka66] G. M. Kalvius and J. K. Tison, Phys. Rev. **152**, 829 (1966).

[Ka68] G. Kaindl, Phys. Letters **28B**, 171 (1968).

[Ka69] G. M. Kalvius, G. K. Shenoy, G. J. Ehnholm, T. E. Katila, O. V. Lounasmaa, and P. Reivari, Phys. Rev. **187**, 1503 (1969).

[Ka70] G. M. Kalvius, T. E. Katila, and O. V. Lounasmaa, in *Mössbauer Effect Methodology* **5**, (Ed. I. J. Gruverman), Plenum Press, New York, 1970, p. 231.

[Ka70a] G. Kaindl and D. Salomon, Phys. Letters **32B**, 364 (1970).

[Ka70b] G. Kaindl, Z. Phys. **240**, 100 (1970).

[Ka71] W. H. Kapfhammer, W. Maurer, F. E. Wagner, and P. Kienle, in *Hyperfine Interactions in Excited Nuclei* (Ed. G. Goldring and R. Kalish), Gordon and Breach Science Publishers, Inc., New York, 1971, p. 839.

[Ka71a] W. H. Kapfhammer, W. Maurer, F. E. Wagner, and P. Kienle, Z. Naturforsch. A **26**, 357 (1971).

[Ka72] G. Kaindl, D. Salomon, and G. Wortmann, Phys. Rev. Letters, **28**, 952 (1972).

[Ka72a] T. E. Katila, V. K. Typpi, G. K. Shenoy, and L. Niinisto, Solid State Commun. **11**, 1147 (1972).

[Ka73] G. Kaindl and D. Salomon, in *Perspectives in Mössbauer Spectroscopy* (Ed. S. G. Cohen and M. Pasternak), Plenum Press, New York, 1973, p. 195.

[Ke53] K. G. Kessler and R. Trees, Phys. Rev. **92**, 303 (1953).

[Ke67] D. Kedem and T. Rothem, Phys. Rev. Letters **18**, 165 (1967).

[Kh68] B. Khurgin, S. Ofer, and M. Rakavy, Nucl. Phys. **A 110**, 577 (1968).

[Kh70] B. Khurgin, S. Ofer, and M. Rakavy, Phys. Letters **33A**, 219 (1970).

[Ki60] O. C. Kistner and A. W. Sunyar, Phys. Rev. Letters **4**, 412 (1960).

[Ki61] O. C. Kistner, A. W. Sunyar, and J. B. Swan, Phys. Rev. **123**, 179 (1961).

[Ki62] P. Kienle, M. Kalvius, F. Stanek, F. Wagner, H. Eicher, and W. Wiedemann, in *Proceedings of the Second International Conference on the Mössbauer Effect* (Ed. D. M. J. Compton and A. H. Schoen), John Wiley and Sons, Inc., New York, 1962, p. 185.

[Ki64] P. Kienle, in *Proceedings of the Third International Conference on the Mössbauer Effect* (Ed. A. J. Bearden), Rev. Mod. Phys. **36**, 372 (1964).

[Ki64a] O. C. Kistner and R. Segnan, Bull. Am. Phys. Soc. **9**, 396 (1964).

[Ki66] O. C. Kistner, Phys. Rev. **144**, 1022 (1966); Erratum: Phys. Rev. **149**, 990 (1966).

[Ki70] H. Kiefte and J. S. M. Harvey, Can. J. Phys. **48**, 562 (1970).

[Ko65] C. W. Kocher, Phys. Letters **14**, 287 (1965).

[Ko71] H. J. Körner, F. E. Wagner, and B. D. Dunlap. Phys. Rev. Letters **27**, 1593 (1971).

[Kr69] V. M. Krasnoperov, A. N. Murin, N. K. Cherezov, and I. A. Yutlandov, Sov. Phys.-Dokl **14**, 458 (1969).

[Ku61] H. Kuiper, Z. Phys. **165**, 402 (1961).

[Ku66] R. N. Kuz'min, N. S. Ibraimov, and G. S. Zhdanov, Zh. Eksp. Teor. Fiz. **50**, 330 (1966)/Sov. Phys.-JETP **23**, 219 (1966).

[Ku68] D. Kucheida, F. Wagner, G. Kaindl, and P. Kienle, Z. Phys. **216**, 346 (1968).

[Ku69] R. N. Kuz'min, A. A. Opalenko, V. S. Shpinel', and I. A. Avenarius, Zh. Eksp. Teor. Fiz. **56**, 167 (1969)/Sov. Phys.-JETP **29**, 94 (1969).

[La62] L. G. Lang, S. DeBenedetti, and R. L. Ingalls, in *Proceedings of the Second International Conference on the Mössbauer Effect* (Ed. D. M. J. Compton and A. H. Schoen), John Wiley and Sons, New York, 1962, p. 168.

[La70] V. A. Lagunov, V. I. Polozenko, and V. A. Stepanov, Fiz. Tverd. Tela., Pis'ma Red. **12**, 3064 (1970)/JETP Letters **12**, 2480 (1970).

[Le70] W. B. Lewis, J. B. Mann, D. A. Liberman, and D. T. Cromer, J. Chem. Phys. **53**, 809 (1970).

[Le70a] H. Lew, Bull. Am. Phys. Soc. **15**, 795 (1970).

[Li53] R. Livingston and H. Zeldes, Phys. Rev. **90**, 609 (1953).

[Li65] I. Lindgren, Ark. Fys. **29**, 553 (1965).

[Lo68] J. C. Love, G. Czjzek, J. J. Spijkerman, and D. K. Snediker, in *Hyperfine Structure and Nuclear Radiations* (Ed. E. Matthias and D. A. Shirley), North-Holland Publ. Co., Amsterdam, 1968, p. 124.

[Lo68a] J. C. Love and F. E. Obenshain, Bull. Am. Phys. Soc. **13**, 667 (1968).

[Lo68b] J. C. Love, G. Czjzek, and F. E. Obenshain, Bull. Am. Phys. Soc. **13**, 250 (1968).

[Lo71] J. C. Love, F. E. Obenshain, and G. Czjzek, Phys. Rev. B **3**, 2827 (1971).

[Lu66] I. I. Lukashevich, V. V. Sklyarevskii, K. P. Aleshin, B. N. Samoilov, E. P. Stepanov, and N. I. Filippov, Zh. Eksp. Teor. Fiz., Pis'ma Red. **3**, 81 (1966)/JETP Letters **3**, 50 (1966).

[Lu67a] A. Lurio, Phys. Rev. **126**, 1768 (1967).

[Ma56] T. E. Manning, M. Fred, and F. S. Tomkins, Phys. Rev. **102**, 1108 (1956).

[Ma65] E. Matthias, S. S. Rosenblum, and D. A. Shirley, Phys. Rev. **139**, B532 (1965).

[Mc71] T. K. McNab and P. H. Barrett, in *Mössbauer Effect Methodology*, **7** (Ed. I. J. Gruverman), Plenum Press, New York, 1971, p. 59.

[Mc71a] T. K. McNab, H. Micklitz, and P. H. Barrett, Phys. Rev. B **4**, 3787 (1971).

[Me72] R. Meeker, G. M. Kalvius, B. D. Dunlap, S. L. Ruby, and D. Cohen, Bull. Am. Phys. Soc. **17**, 85 (1972).

[Me73] R. D. Meeker, B. D. Dunlap, and D. Cohen, private communication.

[Me74] R. D. Meeker, G. M. Kalvius, B. D. Dunlap, S. L. Ruby, and D. Cohen, Nucl. Phys. **A 224**, 429 (1974).

[Mi72] H. Micklitz and P. H. Barrett, Phys. Rev. B **5**, 1704 (1972).

[Mo72] J. A. Monard, P. G. Huray, and J. O. Thomson, Bull. Am. Phys. Soc. **17**, 86 (1972).

[Mo74] J. A. Monard, P. G. Huray, and J. O. Thomson, Phys. Rev. B **9**, 2838 (1974).

[Mu52] K. Murakawa, and S. Suwa, Phys. Rev. **87**, 1048 (1952).

[Mu57] K. Murakawa and T. Kamei, Phys. Rev. **105**, 671 (1957).

[Mu65] W. Müller, A. Steudel, and H. Walther, Z. Phys. **183**, 303 (1965).

[Mu66] E. Münck, D. Quitmann, H. Prange, and S. Hüfner, Z. Naturforsch. A **21**, 1318 (1966).

[Mu66a] E. Münck, S. Hüfner, and D. Quitmann, Z. Naturforsch. A **21**, 2120 (1966).

[Mu66b] E. Münck, D. Quitmann, and S. Hüfner, Z. Naturforsch. A **21**, 847 (1966).

[Mu66c] E. Münck, S. Hüfner, H. Prange, and D. Quitmann, Z. Naturforsch. A **21**, 1507 (1966).

[Mu67] E. Münck, D. Quitmann, and S. Hüfner, Phys. Letters **24B**, 392 (1967).

[Mu68] E. Münck, Z. Phys. **208**, 184 (1968).

[Mu68a] A. H. Muir, Jr., H. Wiedersich, and J. O. Artman, in *Hyperfine Structure and Nuclear Radiations* (Ed. E. Matthias and D. A. Shirley), North-Holland Publ. Co., Amsterdam, 1968, p. 236.

[Na68] A. Narath, Phys. Rev. **165**, 506 (1968).

[Ni63] V. I. Nikolaev, Yu I. Shcherbina, and S. S. Yakimov, Zh. Eksp. Teor. Fiz. **45**, 1277 (1963)/Sov. Phys.-JETP 18, 878 (1964).

[No63] I. Nowik and S. Ofer, Phys. Letters **3**, 192 (1963).

[No63a] I. Nowik and S. Ofer, Phys. Rev. **132**, 241 (1963).

[No65] I. Nowik and H. H. Wickman, Phys. Rev. **140**, A869 (1965).

[No67] A. J. Nozik and M. Kaplan, Phys. Rev. **159**, 273 (1967).

[No67a] I. Nowik, S. Ofer, J. H. Wernick, and H. H. Wickman, Bull. Am. Phys. Soc. **12**, 23 (1967).

[No68] A. J. Nozik, M. Kaplan, and A. I. Weiss, Bull. Am. Phys. Soc. **13**, 894 (1968).

[No71] I. Nowik, E. R. Bauminger, J. Hess, A. Mustachi, and S. Ofer, Phys Letters **34A**, 155 (1971).

[No71a] I. Nowik, in *Hyperfine Interactions in Excited Nuclei* (Ed. G. Goldring and R. Kalish), Gordon and Breach Science Publishers Inc., New York, 1971, p. 769.

[Ob71] L. W. Oberley, N. Hershkowitz, S. A. Wender, and A. B. Carpenter, Phys. Rev. C **3**, 1585 (1971).

[Of65] S. Ofer, M. Rakavy, and E. Segal, Nucl. Phys. **69**, 173 (1965).

[Of65a] S. Ofer, M. Rakavy, E. Segal, and B. Khurgin, Phys. Rev. **138**, A241 (1965).

[Of65b] S. Ofer, E. Segal, I. Nowik, E. R. Bauminger, L. Grodzins, A. J. Freeman, and M. Schieber, Phys. Rev. **137**, A627 (1965).

[Of66] S. Ofer and E. Segal, Phys. Rev. **141**, 448 (1966).

[Of67] S. Ofer and I. Nowik, Nucl. Phys. **A 93**, 689 (1967).

[Ol68] J. R. Oleson and J. C. Walker, Bull. Am. Phys. Soc. **13**, 691 (1968).

[Ol72] L. Olschewshi, Z. Phys. **249**, 205 (1972).

[On64] K. Ono, A. Ito, and T. Fujita, J. Phys. Soc. Jap. **19**, 2119 (1964).

[Ow69] W. R. Owens, B. L. Robinson, and S. Jha, Phys. Rev. **185**, 1555 (1969).

[Pa65] M. Pasternak, A. Simopoulos, and Y. Hazony, Phys. Rev. **140**, A1892 (1965).

[Pa67] M. Pasternak and S. Bukshpan, Phys. Rev. **163**, 297 (1967).

[Pa67a] D. O. Patterson, L. D. Roberts, P. Huray, and J. O. Thomson, Bull. Am. Phys. Soc. **12**, 24 (1967).

[Pa70] D. O. Patterson, J. O. Thomson, P. G. Huray, and L. D. Roberts, Phys. Rev. B **2**, 2440 (1970).

[Pa70a] F. T. Parker, K. A. Hardy, U. Atzmony, and J. C. Walker, Bull. Am. Phys. Soc. **15**, 657 (1970).

[Pa71] F. T. Parker, K. A. Hardy, and J. C. Walker, Phys. Rev. C **3**, 841 (1971).

[Pa71a] F. T. Parker and J. C. Walker, Bull. Am. Phys. Soc. **16**, 23 (1971).

[Pe64] G. J. Perlow, Phys. Rev. **135**, B1102 (1964).

[Pe64a] G. J. Perlow and S. L. Ruby, Phys. Letters **13**, 198 (1964).

[Pe65] G. J. Perlow, C. E. Johnson, and W. Marshall, Phys. Rev. **140**, A875 (1965).

[Pe67] B. Persson, H. Blumberg, and D. Agresti, Phys. Letters **24B**, 522 (1967).

[Pe68] B. Persson, H. Blumberg, and M. Bent, Phys. Letters **27A**, 189 (1968).

[Pe68a] B. Persson, H. Blumberg, and D. Agresti, Phys. Rev. **170**, 1066 (1968).

[Pe68b] B. Persson, H. Blumberg, and D. Agresti, in *Hyperfine Structure and Nuclear Radiations* (Ed. E. Matthias and D. A. Shirley), North-Holland Publ. Co. Amsterdam, 1968, p. 268.

[Pe68c] B. Persson, H. Blumberg and M. Bent, Phys. Rev. **174**, 1509 (1968).

[Pe69] G. J. Perlow, W. Henning, D. Olson, and G. L. Goodman, Phys. Rev. Letters **23**, 680 (1969).

[Pe73] G. J. Perlow, in *Perspectives in Mössbauer Spectroscopy* (Ed. S. G. Cohen and M. Pasternak) Plenum Press, New York, 1973, P. 221.

[Pe73a] G. J. Perlow, L. E. Campbell, L. E. Conroy, and W. Potzel, Phys. Rev. B **7**, 4044 (1973).

[Ph62] E. A. Phillips and L. Grodzins, Bull. Am. Phys. Soc. **7**, 359 (1962).

[Pi68] W. L. Pillinger and J. A. Stone, Bull. Am. Phys. Soc. **13**, 28 (1968).

[Pl71] K. G. Plingen, B. Wolbeck, and F. J. Schroder, Nucl. Phys. **A 165**, 97 (1971).

[Po48] R. V. Pound, Phys. Rev. **73**, 1112 (1948); erratum Phys. Rev. **74**, 228 (1948).

[Pr50] W. G. Proctor, Phys. Rev. **79**, 35 (1950).

[Pr51] W. G. Proctor and F. C. Yu, Phys. Rev. **81**, 20 (1951).

[Pr62] R. S. Preston, S. S. Hanna, and J. Herberle, Phys. Rev. **128,** 2207 (1962).

[Pr68] H. Prange, Z. Phys. **212,** 415 (1968).

[Ra68] D. Raj and S. P. Puri, in *Proceedings Nuclear Physics and Solid State Physics Symposium, 1968* (Physics Comm. of Dept. of At. Eng., India), p. 218.

[Ra70] M. Raymond and S. S. Hafner, Phys. Rev. **1,** 979 (1970).

[Re66] J. Reader, Phys. Rev. **141,** 1123 (1966).

[Ri69] M. Richter, W. Henning, and P. Kienle, Z. Phys. **218,** 223 (1969).

[Ro63] L. D. Roberts and J. O. Thomson, Phys. Rev. **129,** 664 (1963).

[Ro69] A. Rosen, Proc. Phys. Soc., London (At. Mol. Phys.) **2,** 1257 (1969).

[Ro70] M. Rosenberg, S. Mandache, N. Niculescu-Majewska, S. Filotti, and V. Gomolea, Phys. Letters **31A,** 84 (1970).

[Ro70a] M. Rosenberg, S. Mandache, H. Niculescu-Majewska, G. Filotti, and V. Gomolea, J. Appl. Phys. **41,** 1114 (1970).

[Ro72] R. Robinette, J. G. Cosgrove, and R. L. Collins, Nucl. Instr. Methods **105,** 509 (1972).

[Ru66] S. L. Ruby and H. Selig, Phys. Rev. **147,** 348 (1966).

[Ru66a] S. L. Ruby, G. M. Kalvius, R. E. Snyder, and G. B. Beard, Phys. Rev. **148,** 176 (1966).

[Ru67] S. L. Ruby, in *Mössbauer Effect Methodology* **3** (Ed. I. J. Gruverman), Plenum Press, New York, 1967, p. 203.

[Ru67a] S. L. Ruby and C. E. Johnson, Phys. Letters **26A,** 60 (1967).

[Ru67b] S. L. Ruby and G. M. Kalvius, Phys. Rev. **155,** 353 (1967).

[Ru67c] S. L. Ruby, G. M. Kalvius, G. B. Beard, and R. E. Snyder, Phys. Rev. **159,** 239 (1967).

[Ru69] S. L. Ruby, G. M. Kalvius, B. D. Dunlap, G. K. Shenoy, D. Cohen, and D. J. Lam, Phys. Rev. **184,** 374 (1969).

[Ru71] W. Ruegg and J. P. Launaz, Phys. Letters **37A,** 355 (1971).

[Ru74] W. Ruegg, Helv. Phys. Acta **46,** 735 (1974).

[Ry72] S. Rydberg and S. Svanberg, Phys. Scripta **5,** 209 (1972).

[Sa68] C. Sauer, E. Matthias, and R. L. Mössbauer, Phys. Rev. Letters **21,** 961 (1968).

[Sa72] D. Salomon, G. Kaindl, and G. Wortmann, Bull. Am. Phys. Soc. **17,** 86 (1972).

[Sc68] A. Schwenk and G. Zimmerman, Phys. Letters **26A,** 258 (1968).

[Sc70] A. Schwenk, Phys. Letters **31A,** 513 (1970).

[Se65] D. Seyboth, F. E. Obenshain, L. D. Roberts, J. O. Thomson, Bull. Am. Phys. Soc. **10,** 444 (1965).

[Se71] D. Sengupta, J. O. Artman, and G. A. Sawatzky, Phys. Rev. B **4,** 1484 (1971).

[Sh51] R. E. Sheriff and D. Williams, Phys. Rev. **82,** 651 (1951).

[Sh63] N. Shikazono, J. Phys. Soc. Jap. **18,** 925 (1963).

[Sh64] R. R. Sharma and T. P. Das, J. Chem. Phys. **41,** 3581 (1964).

[Sh66] N. Shikazono, H. Takekoshi, and T. Shoji, J. Phys. Soc. Jap. **21,** 829 (1966).

[Sh73] G. K. Shenoy, G. Abstreiter, G. M. Kalvius, K. Schwochau, and K. H. Linse, J. Phys. A **6,** L144 (1973).

[Sk61] V. V. Sklyarevskii, B. N. Samoilov, and E. P. Stepanov, Zh. Eksp. Teor. Fiz. **40,** 1874 (1961)/Sov. Phys.-JETP **13,** 1316 (1961).

[Sm65] K. F. Smith and P. J. Unsworth, Proc. Phys. Soc., London **86,** 1249 (1965).

[Sn66] R. E. Snyder, G. B. Beard, S. L. Ruby, and G. M. Kalvius, Bull. Am. Phys. Soc. **11,** 51 (1966).

[Sn68] R. E. Snyder, J. W. Ross, and D. St. P. Bunbury, Proc. Phys. Soc. (Solid State Phys.) **1,** 1662 (1968).

[So68] W. H. Southwell, D. L. Decker, and H. B. Vanfleet, Phys. Rev. **171,** 354 (1968).

[Sp67] P. W. Spence, M. N. McDermott, Phys. Letters **24A,** 430 (1967).

[Sp67a] P. W. Spence, M. N. McDermott, and D. L. Rump, Bull. Amer. Phys. Soc. **12,** 892 E8 (1967).

[Sp68] J. J. Spijkerman, Symp. Faraday Soc. **1,** 134 (1968).

[Sp74] H. Spiering, R. Zimmermann, and G. Ritter, Phys. Status Solidi B **62,** 123 (1974).

[St59] H. Stroke—private communication. (See G. H. Fuller and V. W. Cohen, Nucl. Data Tables A **5,** 433 (1969)—reference 59S146).

[St63] R. M. Sternheimer, Phys. Rev. **130,** 1423 (1963).

[St63a] J. A. Stone, Bull. Am. Phys. Soc. **8,** 351 (1963).

[St67] R. R. Stevens, Jr., J. S. Eck, E. T. Ritter, Y. K. Lee, and J. C. Walker, Phys. Rev. **158,** 1118 (1967).

[St67a] R. M. Sternheimer, Int. J. Quant. Chem. **1,** 67 (1967).

[St68] M. Stachel, S. Hüfner, G. Crecelius, and D. Quitmann, Phys. Letters **28A,** 188 (1968).

[St68a] J. A. Stone and W. L. Pillinger, Phys. Rev. **165,** 1319 (1968).

[St69] J. Stachel, S. Hufner, G. Crecelius, and D. Quitmann, Phys. Rev. **186,** 355 (1969).

[St70] J. G. Stevens and S. L. Ruby, Phys. Letters **32A,** 91 (1970).

[St70a] J. G. Stevens and L. H. Bowen, in *Mössbauer Effect Methodology*, **5** (Ed. I. J. Gruverman), Plenum Press, New York, 1970, p. 27.

[St71] R. M. Sternheimer and R. F. Peierls, Phys. Rev. A **3,** 837 (1971).

[Su68] J. Sugar, J. Optical Soc. Amer. **58,** 1519 (1968).

[Sw70] L. J. Swartzendruber and L. H. Bennett, J. Res. Nat. Bur. Stand. Sect. A. **74,** 691 (1970).

[Sy71] S. C. Sylvester and D. Schroder, Bull. Am. Phys. Soc. **16,** 25 (1971).

[Sy73] S. C. Sylvester and D. Schroder, Phys. Rev. C **7,** 2056 (1973).

[Th68] J. O. Thomson, P. G. Huray, D. O. Patterson, and L. D. Roberts, in *Hyperfine Structure and Nuclear Radiations* (Ed. E. Matthias and D. A. Shirley), North-Holland Publ. Co., Amsterdam, 1968, p. 557.

[To68] F. F. Tomblin and P. H. Barrett, in *Hyperfine Structure and Nuclear Radiations* (Ed. E. Matthias and D. A. Shirley), North-Holland Publ. Co., Amsterdam, 1968, p. 245.

[Tr68] J. C. Travis and J. J. Spijkerman, in *Mössbauer Effect Methodology* **4**, (Ed. I. J. Gruverman), Plenum Press, New York, 1968, p. 237.

[Tr73] A. Trautwein and F. E. Harris, Phys. Rev. B **7,** 4755 (1973).

[Ul67] J. F. Ullrich and D. H. Vincent, Phys. Letters **25A,** 731 (1967).

[Un69] P. J. Unsworth, Proc. Phys. B (At. Mol. Phys.) **2,** 122 (1969).

[Va72] A. M. van Diepen and R. P. van Stapele, Phys. Rev. B **5,** 2462 (1972).

[Va74] M. van Rossum, G. Langouche, H. Pattyn, G. Dumont, J. Odeurs, A. Meykens, P. Boolchand, and R. Coussement, J. Phys. (Paris), Colloq. C **6,** 35, 639 (1974).

[Vi63] C. E. Violet, R. Booth, and F. Wooten, Phys. Letters **5,** 230 (1963).

[Vi73] C. E. Violet and D. N. Pipkorn, J. Appl. Phys. **42,** 4339 (1971).

[Wa51] H. E. Walchli, R. Livingston and G. Hebert, Phys. Rev. **82,** 97 (1951).

[Wa52] H. E. Walchli, W. E. Leyshon, and F. M. Scheitlin, Phys. Rev. **85,** 479 (1952).

[Wa67] F. Wagner, J. Klöckner, H. J. Körner, H. Schaller, and P. Kienle, Phys. Letters **25B,** 253 (1967).

[Wa67a] F. Wagner, G. Kaindl, P. Kienle, and H. J. Körner, Z. Phys. **207,** 500 (1967).

[Wa68] F. Wagner, G. Kaindl, P. Kienle, and H. J. Körner, in *Hyperfine Structure and Nuclear Radiations* (Ed. E. Matthias and D. A. Shirley), North-Holland Publ. Co., Amsterdam, 1968, p. 187.

[Wa68a] F. Wagner, J. Klöckner, H. J. Körner, H. Schaller, and P. Kienle, in *Hyperfine Structure and Nuclear Radiations* (Ed. E. Matthias and D. A. Shirley), North-Holland Publ. Co., Amsterdam, 1968, p. 77.

[Wa69] F. Wagner, G. Kaindl, H. Bohn, U. Biebl, H. Schaller, and P. Kienle, Phys. Letters **28B,** 548 (1969).

[Wa70] F. E. Wagner, D. Kucheida, G. Kaindl, and P. Kienle, Z. Phys. **230,** 80 (1970).

[Wa71] D. Walcher, Z. Phys. **246,** 123 (1971).

[Wa72] F. E. Wagner, H. Spieler, D. Kucheida, P. Kienle, and R. Wäppling, Z. Phys. **254,** 112 (1972).

[We53] H. E. Weaver, Jr., Phys. Rev. **89,** 923 (1953).

[We61] G. K. Wertheim, Bull. Am. Phys. Soc. **6,** 8 (1961).

[We61a] H. H. F. Wegener and F. E. Obenshain, Z. Phys. **163,** 17 (1961).

[We62] G. K. Wertheim and D. N. E. Buchanan, in *Proceedings of the Second International Conference on the Mössbauer Effect* (Ed. D. M. J. Compton and A. H. Schoen), John Wiley and Sons, Inc., New York, 1962, p. 130.

[Wh69] R. M. Wheeler, U. Atzmony, and J. C. Walker, Phys. Rev. **186,** 1280 (1969).

[Wh73] C. W. White, W. M. Hughes, G. S. Hayne, and H. G. Robinson, Phys. Rev. A **7,** 1178 (1973).

[Wi65] R. Winkler, Phys. Letters **16,** 156 (1965).

[Wi67] F. Wittman, Phys. Letters **24A,** 252 (1967).

[Wi68] J. M. Williams, Proc. Phys. Soc., London (At. Mol. Phys.) **1,** 473 (1968).

[Wi68a] J. W. Wiggins and J. C. Walker, Bull. Am. Phys. Soc. **13,** 672 (1968).

[Wi69] J. W. Wiggins and J. C. Walker, Phys. Rev. **177,** 1786 (1969).

[Wi73] J. M. Williams and J. S. Brook, Phys. Letters **45A,** 335 (1973).

[Wo66] G. K. Woodgate, Proc. Roy. Soc., London A **293,** 117 (1966).

[Wo72] B. Wolbeck and K. Zioutas, Nucl. Phys. A **181,** 289 (1972).

[Wo72a] N. S. Wolmarans and H. de Waard, Phys. Rev. C **6,** 228 (1972).

[Ya51] E. Yasaitis and B. Smaller, Phys. Rev. **82,** 750 (1951).

[Ze68] T. Zemcik, Czech. J. Phys. **18B,** 551 (1968).

[Zi49] J. R. Zimmerman and D. Williams, Phys. Rev. **76,** 350 (1949).

[Zi73] K. Zioutas, B. Wolbeck, and B. Perscheid, Z. Phys. **262,** 413 (1973).