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MÖSSBAUER EFFECT DATA INDEX

Covering the 1976 Literature

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MÖSSBAUER EFFECT DATA INDEX

Covering the 1976 Literature

Foreword

One of the most important – and unfortunately least advertised – applications of nuclear gamma resonance spectroscopy is the organized indexing of scientific information. While there are only two active workers in this field, the rest of us are the beneficiaries of their unique effort which keeps us well informed in our own fields of interest. This tenth volume of *MEDI* is a landmark in an experiment in the distribution of scientific information, initiated by Art Muir and his group. Since 1969, John and Virginia Stevens have explored new ways of gathering

scientific information of interest in our field from all over the world in many languages, and documented, evaluated, and presented this information in a comprehensive format.

It take this opportunity to congratulate the Stevenses for their success, and to express my gratitude to them for their service to all of us. I wish them very good luck.

R. L. MÖSSBAUER

Munich
December, 1977

Acknowledgments

This year our operation was located at the University of Nijmegen, The Netherlands, where we were working during a year leave of absence from UNC-A. In Nijmegen Dr. Jan Trooster was our considerate host and special friend. Others in the Molecular Spectroscopy and the Computer Services divisions were especially helpful as we transferred our system. We are grateful to each person who helped us maintain a nearly normal office and, more important, made us feel at home. Back in the United States Mary Jane Winfrey kept correspondence moving, a formidable task which she performed with commendable efficiency and good cheer.

Over the years many people have conscientiously helped us with various tasks associated with the production of the *Index*. We wish to make note of their assistance and thank them for it publicly. Some of these people have been faithful in their help for several years, for which they deserve special recognition.

Among those in this category are Drs. L. H. Bowen, B. D. Dunlap, and D. Schroeer, who

proofread the data and references, and in so doing demonstrated a special kind of patience and attention to detail. Other longtime assistants are Professor G. N. Belozerskii of USSR and Dr. M. Takano of Japan, both of whom have collected the more obscure literature from their countries and, in many cases, abstracted the data for us. This year Drs. G. K. Shenoy and F. E. Obenshain and Ms. Sheila Hedges took on the task of ferreting out references we needed from their own libraries at Argonne National Laboratory, Oak Ridge National Laboratory, and North Carolina State University, respectively.

Finally, special thanks go to Dr. Stephen Ross-massler, who has been our contact and unfailing mentor with the Office of Standard Reference Data of the U.S. National Bureau of Standards, without whose support this *Index* would not have been possible.

JOHN G. STEVENS
VIRGINIA E. STEVENS

Contents

Foreword	v
Acknowledgments	vii
Instructions on the Use of the Mössbauer Effect Data Index.	1
Arrangement of the Index	3
Abbreviations Used in the 1976 Mössbauer Effect Data Index	5
Isotope Page Information	7
Equipment, Sources, and Supplies for Mössbauer Spectroscopy	9
New England Nuclear	11
The Radiochemical Centre	12
Austin Science Associates	13
Ranger Electronics	14
Elsclint Ltd.	16
The Ealing Corporation	17
Harwell	18
Oxford Instruments	19
Bicron Corporation	20
Tables for Mössbauer Spectroscopy.	21
Condensed Table of Mössbauer Transition Properties	23
Nuclear Radius Results Reported in the 1976 Mössbauer Literature	26
Nuclear Moments Results Reported in the 1976 Mössbauer Literature	27
Mössbauer Periodic Table	28
1976 Data Index.	29
²⁴³ Am (84.0 keV transition)	30
¹⁹⁷ Au (77.3 keV transition)	32
¹³³ Cs (81.0 keV transition)	36
¹⁶⁰ Dy (86.8 keV transition)	38
¹⁶¹ Dy (25.7 keV, 43.8 keV, 74.6 keV transitions)	40
¹⁶⁶ Er (80.6 keV transition)	43
¹⁵¹ Eu (21.5 keV transition)	45
¹⁵³ Eu (83.4 keV, 97.4 keV, 103.2 keV transitions)	48
⁵⁷ Fe (14.4 keV, 136.5 keV transitions)	51
Fine Arts	54
Biological Compounds	54
Inorganic Cyanides	55
Frozen Solutions	56
Glasses and Amorphous Substances	56
Inorganic Halides	57
Irradiation Experiments	58
Metals and Alloys	59
Miscellaneous Experiments	62
Miscellaneous Inorganic Compounds	64
Organic Compounds	66
Inorganic Oxides	74
Source Experiments	77
Inorganic Sulfates	78
Inorganic Sulfides	79
Terrestrial and Extraterrestrial Materials	80
¹⁵⁴ Gd (123.1 keV transition)	83

¹⁵⁵ Gd (60.0 keV, 86.5 keV, 105.3 keV transitions)	85	Glasses and Amorphous Substances.	132
¹⁷⁸ Hf (93.2 keV transition)	88	Inorganic Halides.	132
¹⁹⁹ Hg (158.4 keV transition)	90	Irradiation Experiments	133
¹²⁷ I (57.6 keV transition)	92	Metals and Alloys	134
¹²⁹ I (27.8 keV transition)	94	Miscellaneous Experiments	135
¹⁹¹ Ir (82.4 keV, 129.4 keV transitions)	98	Miscellaneous Inorganic Compounds.	136
¹⁹³ Ir (73.0 keV, 138.9 keV transitions)	101	Organic Compounds	136
⁸³ Kr (9.4 keV transition)	105	Inorganic Oxides	140
⁶¹ Ni (67.4 keV transition)	107	Source Experiments	141
²³⁷ Np (59.5 keV transition)	109	Inorganic Sulfates	141
¹⁸⁹ Os (36.2 keV, 69.6 keV, 95.2 keV transitions).	112	Inorganic Sulfides	141
¹⁹⁵ Pt (98.9 keV, 129.7 keV transitions)	115	Terrestrial and Extraterrestrial Materials	142
¹⁸⁷ Re (134.2 keV transition)	118	¹¹⁹ Sn References	142
⁹⁹ Ru (89.4 keV transition)	120	¹⁸¹ Ta (6.2 keV, 136.2 keV transitions)	152
¹²¹ Sb (37.2 keV transition)	122	¹²⁵ Te (35.5 keV transition)	155
¹⁴⁹ Sm (22.5 keV transition)	126	¹⁶⁹ Tm (8.4 keV transition)	160
¹⁵² Sm (121.8 keV transition)	128	¹⁸² W (100.1 keV transition)	162
¹¹⁹ Sn (23.9 keV transition)	130	¹²⁹ Xe (39.6 keV transition)	164
Biological Compounds.	132	¹⁷⁰ Yb (84.3 keV transition)	166
Frozen Solutions.	132	¹⁷¹ Yb (66.7 keV, 75.9 keV transitions)	168
		⁶⁷ Zn (93.3 keV transition)	171
1976 Topical Reference Lists	173		
Analysis References.	175		
General References	176		
Instrumentation References	177		
Proposal References	179		
Review References	180		
Theory References	184		
Addendum Reference Lists	187		
1971 References	189		
1972 References	189		
1973 References	190		
1974 References	190		
1975 References	195		
1976 Master Reference List.	203		
1976 Alphabetical Author Index.	273		
Cumulative List of Reviews and Useful Papers in Previous MEDI's	356		
Table of Location of Most Recent Isotope Page for Each Mössbauer Isotope	357		

Instructions on the Use of the Mössbauer Data Index

Arrangement of the Index

Isotope Page Information

The Mössbauer data and references for each isotope are preceded by a summary sheet which includes the parent decay schemes and a simplified nuclear level scheme for the isotope, a tabulation of the Mössbauer parameters which have been derived from these properties. The experimental results listed are "selected values" from a critical review of published results. Further details are described on page 7.

Nuclear Transition

The heading on each page gives the Mössbauer isotope and the γ -ray transition energy.

Classifications of Data

Because of the large number of data in the iron and tin sections, these sections are subdivided by grouping the substances studied into several classifications (e.g., Biological Compounds, Inorganic Cyanides, Inorganic Halides, etc.).

Source

Column 1 gives the host material in which the source atoms are embedded. The "=" symbol is used to indicate a continuation of the chemical formula in the remarks column. If the authors do not indicate a source host, the symbol xx is used. When accelerator and related techniques are employed, the appropriate reaction is indicated in parentheses (i.e., n, γ reaction and CE = Coulomb excitation). See page 5 for the abbreviations used in this column.

Source Temperature

Column 2 gives the source temperature in kelvins. R indicates nominal room temperature, N nominal liquid nitrogen temperature, He nominal liquid helium temperature, and H nominal liq-

uid hydrogen temperature. The symbol v is used to indicate a variable-temperature experiment.

Absorber

Column 3 gives the host material in which the absorber atoms are embedded. (See the paragraph on *Source* above for additional remarks.)

Absorber Temperature

Column 4 gives the absorber temperature. (See the paragraph on *Source Temperature* above for additional remarks.)

Isomer Shift

Column 5 gives the isomer (or chemical) shift of the observed spectrum in mm/s. The generally used convention is adopted that the source and absorber have relative motion toward each other for positive velocity. Since most papers do not explicitly state the adopted convention, the sign of the shift may be subject to question. Values are listed without sign if the authors do not indicate the sign. Since a number of authors do not explicitly use the + sign for positive velocity values, it should be remarked that most of the signless shift values are probably positive. If the author specifies some source but lists the shift relative to another source or to a reference absorber, then the given shift values are entered and a notation is made in the source column by listing the source and then listing, in parentheses, IS/the name of the reference material. For example, if the experimenter reports he is using a Cu source but reports his results relative to Fe, under *Source* one would see Cu(IS/Fe).

Quadrupole Splitting

For the case of a pure quadrupole interaction with a nuclear transition between spin 3/2 and

1/2 levels (e.g., ^{57}Fe , ^{119}Sn , ^{169}Tm , etc.), the quadrupole splitting energy, QS, is listed in column 6 in mm/s, where appropriate. This quantity is the peak separation for a simple quadrupole split doublet. QS is usually equal to $\frac{1}{2}e^2qQ(1 + \eta^2/3)^{1/2}$, where e is the electron charge, q the electric field gradient component along the symmetry axis, Q the nuclear quadrupole moment of the 3/2 state, and η the asymmetry parameter. For higher spin states or in the presence of a magnetic interaction, where the situation is more complex, the reporting of quadrupole interaction data is indicated by the symbol “—” in the column. If the quadrupole coupling constant, e^2qQ , has been obtained from the experiment, it is listed in the remarks column. If no units are given with the value listed in the remarks, the units are mm/s. Other units are given with the value.

Remarks

Column 7 gives additional remarks or experimental results. Considerable abbreviation is used here and the user should consult page 5 for these abbreviations. Proper punctuation and syllabization are often ignored because of the limited space. If all the information could not be fitted on one line under remarks, additional lines were used.

Reference Code

Column 8 gives a code to the bibliography. The first two numbers are the year in which the paper was published, the letter is the initial letter of the surname of the first author, and the last three numbers are an arbitrary but unique sequence number.

References

The references for each isotope appear after the data index for that isotope. Following the listing

grouped by isotope, other references appear in the Topical Reference Lists, grouped under these topic code headings: ANALYS = analysis, APPLCN = application, GENRAL = general, INSTRUM = instrumentation, MISCL = miscellaneous, PROPSL = proposal, REVIEW = review, and THEORY = theory. The Addendum Reference List appears after the Topical Reference Lists. This includes articles either not located or else not available prior to the publication of *MEDI-1975*. The information from them is incorporated into the 1976 Data, Topical, and Author Lists. Following the Addendum List is the 1976 Master Reference List, with references listed by reference code in alphanumeric sequence. There is a certain amount of cross-indexing, and some references will therefore appear in more than one topic category. Abbreviations are adopted from Chemical Abstracts' *Source Index*. Titles of French and German papers are in the original language. Special symbols such as accent marks or the German umlaut are not rendered and the spelling is not transliterated (i.e., Mössbauer = MOSSBAUER). Titles of all other international papers are in English. For Soviet and other international journals for which regular translations appear, both the original and translation references are given. In some cases only the name of the journal of the English translation is given; the lack of volume and page numbers indicates the translation was not available at the time this volume went to press. Such translations may now be available; others are many months, even years, behind.

1976 Alphabetical Author Index

This section appears at the end of the 1976 Master Reference List. (Authors with papers in the Addendum List are included in this section as well.) Under the bold heading of each author's name appears an entry for each paper by that author (name in bold type), including co-authors (if any), topic, and reference code.

Abbreviations Used in the 1976 Mössbauer Effect Data Index

A-TEMP=absorber temperature
ABU=aminobutyric acid
AC=aceto
acac=acetylacetonate/acetylacetonato
ACN=acetonitrile
ADN=adenine
AUS=adenosinate
ALA=alanine
aly=alloy
alys=alloys
Am=amyl
AMP=aminophenol
An=aniline
anal=analysis
aph=alpha
APY=aminopyridine
ASD=anisidine

BCA=bovine carbonic anhydrase
BDA=1,4-butylenebis(diphenylarsine)
BDZ=2,2'-bi-4,5-dihydrothiazole
BPD=bis(trifluoromethyl)propane-1,3-dionate
Bipy=bipyridine
BNI=biacetyl-bis-N-methylamine
bond=bonding
BPD=2,2'-bipyridine NN'dioxide
BPO=1,2-bis(diphenylarsine oxide)ethane
BPP=1,3-bis-phenylpropane-1,3-dionate
BPP=1,2-bis(diphenylphosphine oxide)ethane
BQD=bis(1,2-benzoquinone dioximato)
BST=bis(salicylaldehyde) triethylene tetramine
BTZ=2,2'-bi-2-thiazoline
Bu=butyl
Bz=benzoyl
BZ=benzene
BZQ=benzoquinone

c=cis
calc=calculation
calcd=calculated
CE=Coulomb excitation
chem=chemical
chg=charge
CIN=cinchonine
cmpds=compounds
comp=composition
conc=concentration
corln=correlation
Cp=cyclopentadienyl
crln=correlation
crys=crystal
CTD=cyclohepta-2,4,6,-triene,2,7-dione

DAP=1,2 diamino propane
DAZ=diethyldiazodicarboxylate
DBT=N,N'-ditertiarythiourea
DBZ=dibenzoylmethide
decomp=decomposition
DED=diethyl diethylphosphoramidite
DED=diethylacetylene dicarboxylate
DEP=diethyl phenylphosphoramidite
depe=1,2-bis(diethylphosphino)ethane
DET=diethylethylamine
detn=determination
diars=c-phenylenebisdimethylarsine
diphos=C5H5Fe(CO)2SnMe3
dipy=dipyridyl
disbt=distribution
DMA=2,5 dimethoxyaniline
DMD=dimethylacetylene dicarboxylate

DME=dimethyl-N,N'-bis(beta-mercapto-ethyl)ethylenediamine
DMF=N,N-dimethylformamide
DMG=dimethylglyoxime
DML=dimethylaniline
DMN=N,N'-dimethyl-N,N'-bis(2-mercapto-ethyl)-1,3-propanediamine
DMN=2,7-dimethyl-1,8-naphthyridine
DMO=2,5-dimethoxyaniline
DMP=4,5-dimethyl-2-nitrosophenol
dmpe=1,2-bis(dimethylphosphine)ethane
MSO=dimethyl sulfoxide
DMT=4,4'-dimethyl-2,2'-bi-2-thiazoline
DMZ=5,5'-dimethyl-2,2'-bi-2-thiazoline
DPD=1,3-diphenylpropane-1,3-dionate
dpe=Ph2PCH2CH2PPh2 (1,2-bisdi-phenylphioethane)
DPE=diphenylamine
DPG=diphenylglyoximate
DPN=2,14-dimethyl-3,6,10,13,19-penta-azacyclo(13.3.1)nonadeca-1(19),13,15,17-pentaene
DPO=2,13-dimethyl-3,6,9,12,18-penta-azacyclo(12.3.1)octadeca-1(18),2,12,14,16-pentaene
DPP=diphenylpropane-1,3-dionate
dscn=discussion
dte=dithiocarbamate/dithiocarbamate
DTO=1,4-dithiane 1-oxide
DTP=dithiophosphate
DTU=N,N'-dicyclohexylthiourea

EBA=N,N'-ethylenebis(acetylidenimine)
EDA=1,2-ethylenebis(diphenylarsine)
EDIA=ethylenediaminetetraacetic acid/ethylenediaminetetraacetate
efg=electric field gradient
elctplate=electroplate
elec=electronic
ELNG=electronegativity
en=ethylenediamine
EQ=e2qQ (quadrupole coupling constant)
Et=ethyl
eta=asymmetry parameter
ETU=ethylenethiourea
ETX=ethylxanthate
exp=experiment
expl=experimental

f=recoil free fraction
fa=recoil-free fraction of absorber
fs=recoil-free fraction of source

g1=nuclear g factor of the Mössbauer state
ga=gamma
GGL=glycylglycinato
GK=Gol'danskii-Karyagin
GLY=glycine
GMI=glyoxal-bis-N-methylamine

HA=external magnetic field
Hb=deoxyhemoglobin
HBI=4-n-hexoxybenzylidene-4'-iodoaniline
HBF=4-n-hexoxybenzylidene-4'-n-propylaniline
HCA=human carbonic anhydrase
HCT=2-hydroxycyclohepta-2,4,6-trienone
HDA=hexane-1,6 diamine
He=liquid helium temperature(4.2 K)
HEDTA=hydroxyethylethylenediamine triacetate

hex=hexagonal
HFA=hexafluoroacetylacetonato
hfs=hyperfine splitting
HI=internal magnetic field
HIS=histidine
HL=half life
HMP=hexamethylphosphoramide
HQ=8-hydroxyquinoline
Hx=hexyl

ident=identification
IDS=isindioethylenebis(salicylideneimine)
ILC=isoleucine
IME=iminoethyl
info=information
INH=isonicotinic acid hydrazide
INT=intensity
intprtn=interpretation
IQL=isquinoline
IS=isomer shift
Iz=imidazole

LEU=leucine

magn=magnetic/magnetization
Mb=myoglobin
MCH=methylcyclohexane
Me=methyl
MEA=methylamine
mephen=2-methyl-1,10-phenanthroline
MG=nuclear magnetic moment of the ground state
MM=nuclear magnetic moment of the Mossbauer state
MNP=2-methyl-1,8-naphthyridine
MON=5-methoxy-2-nitrosophenol
mono=monoclinic
MOR=morphyl
morph=morpholine
ML=mean life
MPA=methylenebis(diphenylarsineoxide)
MPP=methylenedis(diphenylphosphine oxide)
MTC=monothiocarbamate

N=liquid nitrogen temperature
NCA=nicotinamide
NIO=nioxime
nm=nuclear magneton
NTA=nitrilotriacetate
NNP=1-nitroso-2-naphtholato

obsrv=observation
Oct=octyl
OEP=octaethylporphyrin
OLE=oleate
OMT=octamethyltetraethylporphyrin
OPD=octaethylporphyrin, protoporphyrin
protoporphyrin IX dimethyl ester
ortho=orthorhombic
ox=oxinate/oxine
Ox=8-hydroxyquinoline

P=pressure
PAZ=piperazinium
PBD=1-phenylbutane-1,3-dionate
PBI=2-(2'-pyridyl)benzimidazole
PC=phthalocyanine
pcs=partial chemical shifts
PDA=phenylenediamine
PFC=potassium ferrocyanide
Ph=phenyl
phen=1,10-phenanthroline
PHS=NN'-o-phenylene-bis(salicylidene-
iminate)
pic=picoline
pip=piperidine
PMA=N-(2-pyridylmethylene)aniline
PMC=N-(2-pyridylmethylene)-p-chloroaniline
PMD=N-(2-pyridylmethylene)-p-anisidine
PMI=pyridinal-N-methylamine
PMN=N-(2-pyridylmethylene)-o-chloroaniline
PMO=N-(2-pyridylmethylene)-o-toluidine
PNP=N-(2-pyridylmethylene)-p-toluidine
PMS=N-(2-pyridylmethylene)isopropylamine
PNO=pyrazine mono N-oxide
PPA=piperasine
PPB=phosphoribide
PPD=protoporphyrin IX dimethyl ester dianion
PPH=protoporphyrin
PPT=2-(2-pyridylamino)-4-(2-pyridyl)-
thiazole
pgs=partial quadrupole splittings
Pr=propyl

PRC=procaine
prd=pyrrolidine
prep=preparation
PRL=pyrylium
PID=pentane-2,4-dionate
ptl=phthalate
Py=pyridine
PYR=pyrrolidyl
pyz=pyrazine

QL=quinoline
QM=nuclear quadrupole moment of the Mossbauer state
QND=quinaldine
QS=quadrupole splitting
QUI=quinine
QUN=quinolin-8-olate

R=room temperature
REF=reference
relax=relaxation
rf=radio-frequency
RG=ratio of nuclear g factors
rhomb=rhombohedral
RM=ratio of nuclear magnetic moments(excited to ground)
RQ=ratio of nuclear quadrupole moments(excited to ground)
rxn=reaction

S-TEMP=source temperature (Kelvin)
Salen=N,N'-ethylenebis(salicylideneimine)
SPC=sodium ferrocyanide
SHIFT=isomer shift
SNP=sodium nitroprusside
SOD=second-order Doppler shift
SS=stainless steel
struc=structure

T=temperature
T=tesla
t=trans
TAC=tetraazacyclopentadecane
tach=cis, cis-1,3,5-triamino-cyclohexane
TAE=tris(2-aminoethyl)amine
tame=1,1',1''-tris(aminoethyl)ethane
TAP=tetrakis(p-anisidyl)-porphyrin
TBD=trifluoromethylbutane-2,4-dionate
TBQ=2,3,5,6-tetrachlorobenzoquinone
TC=Curie temperature
TCE=tetracyanoethylene
TCP=tetrakis(p-chlorophenyl)porphyrinate/ or porphyrin
TCQ=tetracyanoquinodimethane
TCZ=thiosemicarbazide
TDT=toluene-3,4-dithiolato
TEA=triethylamine
temp=temperature
terpy=terpyridyl
tet=tetrahedral
TET=triethylenetetraamine
TFA=trifluoroacetylacetonato
TGS=triglycine sulphate
THF=tetrahydrofuran
THR=threonine
thsa=thiosemicarbazone of salicyl-
aldehyde
THT=tetrahydrothiophene
THU=thiourea
TM=Mossbauer temperature
TMB=tetramethyl-p-benzoquinone
TMD=4,4'-tetramethyldiaminodiphenylmethane
TME=tetrakis(p-methoxyphenyl)-porphyrinate
TMP=1,3-bis(trifluoromethyl)propane-
1,3-dionate
TMSO=tetramethylene sulfoxide
TMTU=tetramethylthiourea
To=tolyl
TPE=trimethylolpropanephosphine ester
TPI=tetra(-o-pivalamidophenyl)porphyrin
TPO=alpha, beta, gamma, delta-tetra-(4-
pyridyl)-porphine
TPP=tetraphenylporphyrinate
trans=transition
trew=2,2',2''-triaminotriethylamine
trs=trans
TTF=tetrathiafulvalenium
TU=thiourea

v=variable

W=width
w=with

Isotope Page Information

The following information is presented on each Isotope Page: the (simplified) decay scheme (the Mössbauer transitions are shown with broader lines); the γ -ray energies [E_γ] and relative intensities [I_{parent}] (where available); the half-life [$t_{1/2}$] and the total internal conversion coefficient [α_T] of the Mössbauer transition; the natural isotopic abundance [IA] of the isotope; the magnetic moments [μ (ground state dipole moment), μ^* (Mössbauer state dipole moment)] and quadrupole moments [Q (ground state quadrupole moment), Q^* (Mössbauer state quadrupole moment)] of the levels between which the transition occurs; the ratio of nuclear moments [R_μ (dipole moment ratio of Mössbauer state to ground state), R_Q (quadrupole moment ratio of Mössbauer state to ground state)]; and special references and notes, if any. R_μ and R_Q values are given in preference to μ^* and Q^* values. All μ values have been corrected for diamagnetic shielding, using Kopfermann's calculations.¹ If the "Mössbauer level" is depopulated by more than one transition, the fraction of decays branching through the Mössbauer transition is indicated [ρ] in percent (e.g., see ¹⁶¹Dy). When experimental values for the total internal conversion coefficient are not available, theoretical values are determined from a computer program of Hager and Seltzer.² When more than one measured value is considered a weighted mean is used.

¹ H. Kopfermann, *Nuclear Moments* (translated by E.E. Schneider) (Academic Press, New York, 1958).

² R.S. Hager and E.C. Seltzer, *Nuclear Data Tables A4*, 1 (1968).

The listed Mössbauer parameters and energy conversions were computer calculated from the adopted measured parameters using the equations given in *Mössbauer Effect Data Index* 1958–1965.³ Their uncertainties are propagated from the measured values by standard statistical procedures. When more than one value is available the reported number is the weighted mean. Values used for the physical constants are as follows:

$$\begin{aligned} h &= 6.626196(30) \times 10^{-34} \text{ J}\cdot\text{s},^4 \\ c &= 2.997924562(11) \times 10^8 \text{ m/s},^5 \\ e &= 1.6021917(70) \times 10^{-19} \text{ C}.^4 \end{aligned}$$

The energies of the $K\alpha_1$ x-rays were obtained from Table 12 in the *Table of Isotopes*.⁶ Also obtained from this reference were some of the simplified energy level diagrams and decay schemes. Extensive use was made of the Nuclear Data Sheets, compiled by the Nuclear Data Group at Oak Ridge National Laboratory (Academic Press, New York). Reference code numbers are used for any reference in any volume of the *Mössbauer Effect Data Index*.

³ A.H. Muir, Jr., K.J. Ando, and H.M. Coogan, *Mössbauer Effect Data Index 1958–1965* (Interscience Publishers, New York, 1966), p. xvi.

⁴ B.N. Taylor, W.H. Parker, and D.N. Langenberg, *Rev. Mod. Phys.* **41**, 375 (1969).

⁵ K.M. Evenson, J.S. Wells, F.R. Peterson, B.L. Danielson, G.W. Day, R.L. Barger, and J.L. Hall, *Phys. Rev. Lett.* **29**, 1346 (1972).

⁶ C.M. Lederer, J.M. Hollander, and I. Perlman, *Table of Isotopes*, Sixth Edition (John Wiley & Sons, New York, 1967), p. 570.

Equipment, Sources, and Supplies for Mössbauer Spectroscopy