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MÖSSBAUER SPECTROSCOPY SOURCE MATERIALS AND THEIR PROPERTIES

Zbigniew M. Stadnik
Institute of Physics
Jagiellonian University
Cracow, Poland

A good Mössbauer source should emit a monochromatic line whose width is very close to natural Heisenberg width Γ_{nat} and should have a substantial fraction of zero-phonons f_s. Source materials selected for inclusion in the table are those for which these two parameters are the best currently known. For these materials values of f_s are compiled from the literature. Some of the values have been calculated using standards statistical procedures, the details of which are described elsewhere.[1] Uncertainties of f_s, given in parentheses, indicate calculated standard deviation; e.g., 0.784(9) = 0.784 ± 0.009. For some source materials there are no experimental data on f_s available. For these materials only the suitable source temperature T_s is given.

Footnotes for isotopes in the table contain details of source preparation plus relevant references. Other information and references on those sources which may be of special interest to the readers are available from the author.

Source Materials and Their Properties

Isotope	E_γ(keV)	Γ_{nat}(mm/s)	Footnote	Source Material	T_s(K)	f_s
^{57}Fe	14.41	0.194	a	Cr	300	0.784(9)
				SS310	300	0.604(47)
				SS	300	0.678(20)
				Rh	300	0.784(13)
					4.2	0.875(18)
				Pd	300	0.660(1)
					77	0.863(2)
					4.2	0.813(17)
				Cu	300	0.708(1)
					4.2	0.910(2)
				Pt	300	0.724(2)
					77	0.890(4)
					4.2	0.851(53)
				CoO	300	0.735(27)
^{61}Ni	67.41	0.770	b	Ni-Cr alloy	4.2	
				Ni-V alloy	4.2	0.162(3)
^{99}Ru	89.36	0.149	c	Ru(Rh)	4.2	0.140(50)
^{119}Sn	23.87	0.646	d	SnO_2	300	0.471(28)
					77	0.585(35)
					4.2	0.885(15)
				$CaSnO_3$	300	0.574(17)
				$BaSnO_3$	300	0.623(21)
				Pd(Sn)	300	0.383(29)
				Pd_3Sn	300	0.340(50)
					4.2	0.750(15)
				V(Sn)	300	0.460(30)
					77	0.780(30)
				Mg_2Sn	300	0.280(26)
					77	0.770(80)

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Source Materiols and Their Properties (continued)

Isotope	E_γ(keV)	Γ_{nat}(mm/s)	Footnote	Source Material	T_s(K)	f_s
^{119}Sn	23.87	0.646	d	α-Sn	77	
				β-Sn	300	0.046(3)
					77	0.446(12)
					4.2	0.716(16)
^{121}Sb	37.15	2.10	e	SnO_2	300	0.212(21)
					77	0.320(31)
				$BaSnO_3$	77	0.450(50)
				β-Sn	77	0.160(20)
				$Ni_{21}Sn_2B_6$	300	0.070(20)
					77	0.290(50)
^{125}Te	35.46	5.209	f	β-TeO_3	300	0.320(40)
					77	0.531(23)
				PbTe	300	<0.029
					77	0.250(32)
				Cu(I)	77	0.143(30)
					4.2	0.400(50)
				Rh(Sb)	4.2 to 77	
				Cu(Sb)	300	<0.029
					77	0.442(59)
^{127}I	57.60	2.49	g	ZnTe	4.2	0.120(24)
^{129}I	27.77	0.586	h	ZnTe	77	0.232(43)
^{149}Sm	22.49	1.708	i	Eu_2O_3	300	
				EuF_3	300	
^{151}Eu	21.53	1.31	j	SmF_3	300	0.275(125)
				$SmF_3 \cdot 2H_2O$	300	
				Sm_2O_3	300	0.440(60)
^{153}Eu	103.2	0.68	k	Sm_2O_3	20	0.050(10)
^{155}Gd	86.55	0.499	l	Pd(Eu)	4.2	0.110(10)
				Sm(Eu)	4.2	
				$Sm_2Sn_2O_7$	4.2	
^{161}Dy	26.66	0.378	m	Gd_2O_3	300	0.230(50)
				GdF_3	300	
				Gd(Tb)	300	
^{166}Er	80.56	1.816	n	$HoAl_2$	25-30	
^{170}Yb	84.25	2.019	o	TmB_{12}	4.2	0.340(10)
				$TmAl_2$	4.2	0.180(10)
				Tm	4.2	
^{181}Ta	6.24	0.0064	p	Mo(W)	300	
				W	300	
				Ta(W)	300	
				Pt(W)	300	
^{182}W	100.1	2.09	q	Ta	4.2	0.150(30)
^{193}Ir	73.04	0.595	r	Pt(Os)	4.2	
				Os	4.2	
				Nb(Os)	4.2	
				V(Os)	4.2	

Source Materials and Their Properties (continued)

Isotope	E_γ (keV)	Γ_{nat} (mm/s)	Footnote	Source Material	T_s (K)	f_s
^{195}Pt	98.86	16.28	s	Pt(Au)	20	0.089(2)
					77	0.021(3)
				Pt	4.2	
				Ir(Au)	20	0.0523(5)
^{197}Au	77.35	1.882	t	Pt	77	0.069(5)
					4.2	0.272(26)
^{237}Np	59.54	0.067	u	Th(Am)	4.2 to 77	
				VO_2	4.2 to 77	

(a) The 14.41 keV level is populated by electron capture decay of ^{57}Co (which is the most frequent route of population), by Coulomb excitation, and by nuclear reaction. The parent nucleus ^{57}Co is produced by irradiating an iron target with 9.5-MeV deuterons (for this energy this process is the most efficient) by the reaction $^{56}Fe(d,n)^{57}Co$. After irradiation the target is dissolved in mineral acids. The radioactive carrier free ^{57}Co is obtained by isopropyl ether extraction, which is followed by an ion exchange separation. Next, the carrier free ^{57}Co is deposited on the surface of a suitable matrix by means of the electrolytic method or by evaporation to dryness of ^{57}Co salt solution. Then ^{57}Co is diffused into the matrix by annealing at an appropriotely high temperature in vacuum or in inert gas atmosphere during a suitable period of time.

At the initial stage of development of Mössbauer spectroscopy the commonly used source was ^{57}Co in stainless steel because of its easy preparation. However, it emitted a considerably broadened line due to the existence of various impurities and large resonance self-absorption in stainless steel. The best single line sources are ^{57}Co in Pt, Pd, Cu and Cr matrices, of which ^{57}Co in Cr has the largest f_s and ^{57}Co in Pd the smallest. The intermediate values of f_s, approximately equal, are characteristic for ^{57}Co in Pt and Cu matrices the linewidths of the sources ^{57}Co in Cu, Pt and Pd are very close to the natural linewidth. The ^{57}Co in Cr source emits a slightly broadened line, but if suitable source preparation procedure is employed this source also gives an unbroadened line.[2] The disadvantage of ^{57}Co in Pt, ^{57}Co in Pd sources is comparatively large atomic absorption (large Z). There are some difficulties in producing thin Cr foils for the ^{57}Co in Cr source and the use of thick foils requires very precise homogeneous distribution of ^{57}Co in the surface layer. The ^{57}Co in Cu source is not chemically stable; Cu has very low solubility for Fe and Co, and it gives on anomalously asymmetric line. This asymmetry may be removed by appropriate source preparation.[3] The source in the form of ^{57}Co in CoO has also very good parameters.[4] ^{57}Co in Cr seems to be the best source at 300 K and ^{57}Co in Rh at 4.2 K.

In certain experiments, such as investigation of the Mössbauer effect in scattering geometry or under high pressures, strong sources are needed. The increase in source activity deteriorates the source parameters on account of considerable broadening of the emission line caused by resonance self-absorption. This resonance broadening seems to be the limiting factor for strong sources. ^{57}Co in stainless steel is better as a strong source than ^{57}Co in Cu and Pd. It was found that non-ferromagnetic compounds of high Co content may be used as high-activity sources.[5] They have high f_s and emit single broadened lines. CoO is also a good matrix for a high-activity source.

Mössbauer experiments using polarized gamma radiation give significant simplification of complex spectra and yield a considerable amount of information, not, or with difficulty, obtainable by means of unpolarized radiation. The difficulty lies in producing a source emitting a single line of definite polarization. The simplest palarized source is ^{57}Co in an iron foil magnetized in the proper direction, but the emission line is not monochromatic and the absorption spectra are complex. A better polarized source, although emitting two lines, is ^{57}Co embedded into a suitable monocrystal. A single line source of definite polarization

may be obtained using a suitable moving filter (this requires two driving systems) or a motionless properly prepared filter.

References: 2-7.

(b) The radioactive decay of ^{61}Co, produced by ^{64}Ni(p,α)^{61}Co, ^{62}Ni(γ,p)^{61}Co reactions, and ^{61}Cu, produced by ^{63}Cu(γ,2n)^{61}Cu, ^{60}Ni(d,n)^{61}Cu, ^{58}Ni(α,n)^{61}Zn $\xrightarrow{\text{electron capture decay}}$ ^{61}Cu reactions, both populate the 67.41 keV level of ^{61}Ni. The ^{61}Cu parent nucleus has not been utilized as often as ^{61}Co because of the complexity of the decay scheme and the difficulty in its production. The emission line of the sources using Ni matrix is broadened owing to magnetic hyperfine interactions. The cubic matrices prepared by alloying either chromium or vanadium with Ni (about 15% Cr or V) proved to be very useful because the Curie point of nickel decreases rapidly with the addition of these elements. At 4.2 K ^{61}Co in these matrices gives a single line very close in width to Γ_{nat}.

Reference: 8.

(c) The parent nucleus ^{99}Rh may be produced by ^{99}Ru(p,n)^{99}Rh or by ^{99}Ru(d,2n)^{99}Rh reaction. A ruthenium metal host lattice, even though it has a hexagonal structure, was used in all reported studies. The ^{99}Rh in Ru source gives a single line. A slight broadening is caused by quadrupole interaction and resonance self-absorption in the Ru matrix. The source produced by Ru bombardment without further chemical treatment shows an appreciably smaller f_s than that produced by chemical separation of ^{99}Rh activity followed by re-incorporation into Ru metal. Cubic Rh may be used as a source material but it has a much lower f_s.

Reference: 9.

(d) The 23.87 keV level is populated by isomeric transition in ^{119m}Sn, produced through ^{118}Sn(n,γ)^{119m}Sn reaction, or by electron capture decay of ^{119}Sb produced by ^{119}Sn(p,n)^{119}Sb or ^{120}Sn(p,2n)^{119}Sb reaction. In nearly all sources isomeric transition in ^{119m}Sn is employed. The sources used in early measurements were ^{119m}Sn in SnO_2 and Sn. The ^{119m}Sn in SnO_2 source has a high f_s at 300 K but there are some problems in precise definition of its stoichiometry and the width of its emission line is more than two times greater than Γ_{nat}. The main disadvantage of ^{119m}Sn in α-Sn and β-Sn sources, apart from line broadening, is a very low f_s at 300 K. The ^{119m}Sn in Mg_2Sn source gives a slightly broadened line but it has a rather small f_s at 300 K, hence either cooling of the source or long-data accumulation time is required. Furthermore, Mg_2Sn is chemically unstable when exposed to moisture, resulting in an increase in emission linewidth. A very good source, now frequently used, is ^{119m}Sn in $BaSnO_3$. It emites a single line very close in width to Γ_{nat} and has a high f_s at 300 K. The Pd(Sn) source material also has good parameters at 300 K. However, apart from the $Pd_{0.97}Sn_{0.03}$ matrix, there may exist different Pd_xSn_y compounds, since Pd_xSn_y is a substitutional type alloy, resulting in broadened of the emission line. Good sources, though less often used, are ^{119m}Sn in Pd_3Sn and $CaSnO_3$.

References: 10-14.

(e) The 37.15 keV level is entirely populated by β^--decay of ^{121m}Sn produced by ^{120}Sn(n,γ)^{121m}Sn reaction. The first source used was ^{121m}Sn in β-Sn, but it had a small value of f_s and gave a slightly broadened line owing to the non-cubic β-Sn matrix. The sources mainly employed now are ^{121m}Sn in SnO_2, $BaSnO_3$, $CaSnO_3$ and $Ni_{21}Sn_2B_6$ matrices. All these sources emit slightly broadened single lines. The stannate sources are probably preferable to ^{121m}Sn in SnO_2 sources because of the higher f_s of the former and the non-cubic symmetry of the latter. All the above-mentioned sources, except ^{121m}Sn in $Ni_{21}Sn_2B_6$, show very large isomer shifts relative to InSb, which means that a large velocity scale is required for the investigation of Sb compounds. The ^{121m}Sn in $Ni_{21}Sn_2B_6$ source does not have this disadvantage. Its parameters are comparable with the other sources at 77 K.

Reference: 15.

(f) The 35.46 keV level of ^{125}Te may be populated by β^- - decay of ^{125}Sb, produced via $^{124}Sn(n,\gamma)^{125m}Sn \xrightarrow{\beta^- - decay} {}^{125}I$ reaction; or isomeric transition in ^{125m}Te, produced through $^{124}Te(n,\gamma)^{125m}Te$ reaction. The source with the highest f_s is ^{125m}Te in β-TeO_3. Its only disadvantage is a short half-life (fifty eight days) of the metastable ^{125m}Te state. The sources in which the parent nucleus is ^{125}Sb ($t_{\frac{1}{2}} = 2.7$ years) do not have this drawback. From them ^{125}Sb in Rh has been found to be the best. The sources using ^{125}I parent nucleus have substantially worse parameters.

References: 16, 17.

(g) The parent nucleus ^{127m}Te is produced via $^{126}Te(n,\gamma)^{127m}Te$ reaction. The commonly used source is ^{127m}Te in ZnTe which emits a single line very close in width to Γ_{nat}. The $Te(OH)_6$ and Te matrices have been less satisfactorily used.

References: 18, 19.

(h) The parent nuclei ^{129m}Te and ^{129}Te of ^{129}I Mössbauer isotope are obtained by $^{128}Te(n,\gamma)$ reaction. The matrix generally used is ZnTe. The value of f_s for the ^{129m}Te in ZnTe source is about four times smaller than for the ^{129}Te in ZnTe source and hence tended to be preferred in Mössbauer spectroscopy of the latter. However, the short half-life restricts its applicability to laboratories not too far from a reactor.

Reference: 20.

(i) The parent nucleus ^{149}Eu is obtained by $^{150}Sm(p,2n)^{149}Eu$ or $^{149}Sm(p,n)^{149}Eu$ reaction, or by a spallation by irradiation of Ta with protons. The irradiated Sm_2O_3 may be directly used as the source or ^{149}Eu activity may be separated by ion-exchange techniques and incorporated into Eu_2O_3. There is no resonance self-absorption in the latter source. A good source is ^{149}Eu in EuF_3. It emits a slightly broadened line due to unresolved quadrupole interaction and paramagnetic hyperfine effects. All sources are used at room temperature since lower temperatures produce substantial line broadening owing to paramagnetic hyperfine effects.

Reference 21.

(j) This Mössbauer level may be populated by electron capture decay of ^{151}Gd, produced by $^{151}Eu(p,n)^{151}Gd$ or $^{151}Eu(d,2n)^{151}Gd$ reaction, β^- - decay of ^{151}Sm, produced by $^{150}Sm(n,\gamma)^{151}Sm$ reaction, and by Coulomb excitation. ^{151}Gd in Nd_2O_3 and Eu_2O_3, and ^{151}Sm in Sm_2O_3 and in SmF_3 give a single line without appreciable hyperfine broadening and have a high f_s at 300 K. In an Coulomb excitation experiment the Eu_2O_3 target emits a single, slightly broadened line.

Reference: 22.

(k) The 103.2 keV level is populated by electron capture decay of ^{153}Gd, produced by $^{152}Gd(n,\gamma)^{153}Gd$, $^{153}Eu(d,2n)^{153}Gd$, $^{153}Eu(p,n)^{153}Gd$ reactions, or by β^- -decay of ^{153}Sm, produced by $^{152}Sm(n,\gamma)^{153}Sm$ reaction. A widely used source is ^{153}Sm in Sm_2O_3. It emits a single line width of about $2\Gamma_{nat}$. The ^{153}Sm in $SmPd_3$ source gives a narrower emission line.

References: 23, 24.

(l) The parent nucleus ^{155}Eu is produced via $^{154}Sm(n,\gamma)^{155}Sm \xrightarrow{\beta^- - decay} {}^{155}Eu$ reaction. The sources initially used, ^{155}Eu in Sm_2O_3 and in SmH_2, give split emission lines. The sources in $YbAl_2$ and $Sm_{0.05}Al_{0.95}$ matrices suffer from line broadening. Good parameters are characteristic for the sources of ^{155}Eu in $Sm_2Sn_2O_7$, Pd, $SmPd_3$.

References: 25,26

(m) The parent nucleus ^{161}Tb is produced by $^{160}Gd(n,\gamma)^{161}Gd \xrightarrow{\beta^- - decay} {}^{161}Tb$ reaction. The sources ^{161}Tb in Gd_2O_3 and in Dy_2O_3 used initially emit single, very broad lines. Their linewidths are two orders of magnitude greater than Γ_{nat}. The ^{161}Tb in Mg and ^{161}Tb in Mo sources emit slightly narrower lines. This broadening is caused by paramagnetic relaxation

effects. The ^{161}Tb in $Gd_{0.5}Dy_{0.5}F_3$ and ^{161}Tb in GdF_3 sources are much better than those mentioned above. The sharpest line is emitted from the ^{161}Tb in $Gd_2Ti_2O_7$ source but its temperature must be kept at 150 K.

References: 27, 28.

(n) The parent nucleus ^{166}Ho is obtained via the reaction $^{165}Ho(n,\gamma)^{166}Ho$. The source ^{166}Ho in Ho_2O_3 used at the beginning gives a very broad line. A better source, widely used now, is ^{166}Ho in $HoAl_2$ whose linewidth is about three times greater than Γ_{nat} but it must be kept at 25–30 K in order to avoid magnetic hyperfine splittings. The ^{166}Ho in $Ho_{0.15}Y_{0.85}Al_2$ source also gives an unsplit line but it may be kept at lower temperatures than the Curie point (27 K) of the $HoAl_2$ matrix. The single line source ^{166}Ho in $(Ho_{0.4}Y_{0.6})H_2$ matrix may be used at 4.2 K and its preparation is easy.

Reference: 29.

(o) The parent nucleus ^{170}Tm is produced by $^{169}Tm(n,\gamma)^{170}Tm$ reaction. The sources generally used are ^{170}Tm in $TmAl_2$, in $Tm_{0.1}Al_{0.9}$, and in TmB_{12}. The last source has the highest f_s.

References: 30, 31.

(p) The parent nucleus ^{181}W is obtained by $^{180}W(n,\gamma)^{181}W$, $^{181}Ta(d,2n)^{181}W$ or $^{181}Ta(p,n)^{181}W$ reactions. The difficulties in preparing a good source lie in the large quadrupole moment of ^{181}Ta, hence any electric field gradients produced by impurities and lattice imperfections cause an appreciable broadening of the emission line as compared with a very small value of Γ_{nat}. From among the different source matrices used, the most suitable is a tungsten matrix.

Reference: 32.

(q) This level may be populated by β^- - decay of ^{182}Ta produced by $^{181}Ta(n,\gamma)^{182}Ta$ or $^{181}Ta(d,p)^{182}Ta$ reactions, or by Coulomb excitation. The commonly used radioactive source is ^{182}Ta in cubic Ta lattice. This gives a single line very close in width to Γ_{nat} and has a reasonably high f_s at low temperatures. In the case of Coulomb excitation, the W targets emit slightly broadened single lines and have a lower f_s as a result of radiation damage or localized heating effects.

References: 33, 34.

(r) The parent nucleus ^{193}Os is produced by $^{192}Os(n,\gamma)^{193}Os$ reaction. Owing to the non-zero electric field gradient at the nuclear sites in the hexagonal osmium lattice, the emission line of the commonly used source ^{193}Os in Os is an unresolved quadrupole doublet. The sources of ^{193}Os in Pt, Nb and V emit sharper lines.

Reference: 35.

(s) This level is populated by electron capture decay of ^{195}Au or by isomeric transition in ^{195m}Pt. ^{195}Au is produced by the $^{195}Pt(d,2n)^{195}Au$ or $^{195}Pt(p,n)^{195}Au$ reaction, and ^{195m}Pt may be obtained by $^{194}Pt(n,\gamma)^{195m}Pt$ reaction. The main disadvantage of the very often used sources ^{195}Au in Pt, ^{195m}Pt in Pt is the resonance self-absorption in the source matrix. The disadvantage mentioned above is avoided by using Ir and Cu matrices. The ^{195}Au in Ir, ^{195}Au in Cu sources emit single, only slightly broadened lines.

References: 36, 37.

(t) The 77.35 keV level may be populated by β^- - decay of ^{197}Pt, obtained by $^{196}Pt(n,\gamma)^{197}Pt$ reaction, or electron capture of ^{197}Hg, produced by $^{196}Hg(n,\gamma)^{197}Hg$. The ^{197}Pt parent nucleus is widely used because it gives a simpler photon spectrum than ^{197}Hg. The best matrix for ^{197}Pt is Pt. The linewidth of such source at 4.2 K is very close to Γ_{nat}.

Reference: 38

(u) The 59.54 keV level of ^{237}Np may be populated by β^--decay of ^{237}U, produced by $^{236}U(n,\gamma)$ reaction, α-decay of ^{241}Am, and electron capture of ^{237}Pu, obtained via $^{237}Np(d,2n)^{237}Pu$ reaction, the latter not being employed on account of difficulties in preparation. In almost all Mössbauer studies ^{241}Am parent nucleus is employed because of its longer half-life and cleaner gamma-spectrum as compared with ^{237}U. $^{241}AmO_2$ in NpO_2, $^{237}UO_2$ in NpO_2, ^{241}Am in Am and in Cu give single lines thirty times broader in width than Γ_{nat}. ^{241}Am in non-metallic compound AmO_2 shows multiple emission lines. The best source thus far is ^{241}Am in Th, giving the narrowest line which is still more than fifteen times broader than Γ_{nat}. Reference: 39.

Much useful information on the methodology of many Mössbauer isotopes can be found in Reference 40. This survey covers the literature through June, 1977. More detailed data and information on any isotope may be obtained from the author. Both the author and the staff at the Mössbauer Effect Data Center would appreciate receiving additional information, published or unpublished, which will add to or modify the material presented above.

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