e

$J = \frac{1}{2}$

e MASS (atomic mass units u)

The primary determination of an electron's mass comes from measuring the ratio of the mass to that of a nucleus, so that the result is obtained in u (atomic mass units). The conversion factor to MeV is more uncertain than the mass of the electron in u; indeed, the recent improvements in the mass determination are not evident when the result is given in MeV. In this datablock we give the result in u, and in the following datablock in MeV.

VALUE (10^{-6} u)		*DOCUMENT ID*		*TECN*	*COMMENT*
548.5799090441	**±0.0000000097**	MOHR	25	RVUE	2022 CODATA value
• • • We do not use the following data for averages, fits, limits, etc. • • •					
548.579909065	±0.000000016	TIESINGA	21	RVUE	2018 CODATA value
548.579909070	±0.000000016	MOHR	16	RVUE	2014 CODATA value
548.57990946	±0.00000022	MOHR	12	RVUE	2010 CODATA value
548.57990943	±0.00000023	MOHR	08	RVUE	2006 CODATA value
548.57990945	±0.00000024	MOHR	05	RVUE	2002 CODATA value
548.5799092	±0.0000004	[1] BEIER	02	CNTR	Penning trap
548.5799110	±0.0000012	MOHR	99	RVUE	1998 CODATA value
548.5799111	±0.0000012	[2] FARNHAM	95	CNTR	Penning trap
548.579903	±0.000013	COHEN	87	RVUE	1986 CODATA value

[1] BEIER 02 compares Larmor frequency of the electron bound in a $^{12}C^{5+}$ ion with the cyclotron frequency of a single trapped $^{12}C^{5+}$ ion.

[2] FARNHAM 95 compares cyclotron frequency of trapped electrons with that of a single trapped $^{12}C^{6+}$ ion.

e MASS

The mass is known more precisely in u (atomic mass units) than in MeV. The conversion is: 1 u = 931.494 103 72(29) MeV/c^2 (2022 CODATA value, MOHR 25). The conversion error dominates the uncertainty of the masses given below.

VALUE (MeV)		*DOCUMENT ID*		*TECN*	*COMMENT*
0.51099895069	**±0.00000000016**	MOHR	25	RVUE	2022 CODATA value
• • • We do not use the following data for averages, fits, limits, etc. • • •					
0.51099895000	±0.00000000015	TIESINGA	21	RVUE	2018 CODATA value
0.5109989461	±0.0000000031	MOHR	16	RVUE	2014 CODATA value
0.510998928	±0.000000011	MOHR	12	RVUE	2010 CODATA value
0.510998910	±0.000000013	MOHR	08	RVUE	2006 CODATA value
0.510998918	±0.000000044	MOHR	05	RVUE	2002 CODATA value
0.510998901	±0.000000020	[1,2] BEIER	02	CNTR	Penning trap
0.510998902	±0.000000021	MOHR	99	RVUE	1998 CODATA value
0.510998903	±0.000000020	[1,3] FARNHAM	95	CNTR	Penning trap
0.510998895	±0.000000024	[1] COHEN	87	RVUE	1986 CODATA value
0.5110034	±0.0000014	COHEN	73	RVUE	1973 CODATA value

[1] Converted to MeV using the 1998 CODATA value of the conversion constant, 931.494013 ± 0.000037 MeV/u.

[2] BEIER 02 compares Larmor frequency of the electron bound in a $^{12}C^{5+}$ ion with the cyclotron frequency of a single trapped $^{12}C^{5+}$ ion.

[3] FARNHAM 95 compares cyclotron frequency of trapped electrons with that of a single trapped $^{12}C^{6+}$ ion.

$(m_{e^+} - m_{e^-}) / m_{\text{average}}$

A test of *CPT* invariance.

VALUE	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
$<8 \times 10^{-9}$	90	[1] FEE	93	CNTR	Positronium spectroscopy
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$<4 \times 10^{-23}$	90	[2] DOLGOV	14		From photon mass limit
$<4 \times 10^{-8}$	90	CHU	84	CNTR	Positronium spectroscopy

[1] FEE 93 value is obtained under the assumption that the positronium Rydberg constant is exactly half the hydrogen one.

[2] DOLGOV 14 result is obtained under the assumption that any mass difference between electron and positron would lead to a non-zero photon mass. The PDG 12 limit of 1×10^{-18} eV on the photon mass is in turn used to derive the value quoted here.

$\left|q_{e^+} + q_{e^-}\right| / e$

A test of *CPT* invariance. See also similar tests involving the proton.

VALUE	*DOCUMENT ID*		*TECN*	*COMMENT*
$<4 \times 10^{-8}$	[1] HUGHES	92	RVUE	
• • • We do not use the following data for averages, fits, limits, etc. • • •				
$<2 \times 10^{-18}$	[2] SCHAEFER	95	THEO	Vacuum polarization
$<1 \times 10^{-18}$	[3] MUELLER	92	THEO	Vacuum polarization

[1] HUGHES 92 uses recent measurements of Rydberg-energy and cyclotron-frequency ratios.

[2] SCHAEFER 95 removes model dependency of MUELLER 92.

[3] MUELLER 92 argues that an inequality of the charge magnitudes would, through higher-order vacuum polarization, contribute to the net charge of atoms.

e MAGNETIC MOMENT ANOMALY

$\mu_e/\mu_B - 1 = (g{-}2)/2$

VALUE (units 10^{-6})	*DOCUMENT ID*		*TECN*	*CHG*	*COMMENT*
1159.65218062±0.00000012 OUR AVERAGE					
1159.65218059±0.00000013	[1] FAN	23	MRS		Single electron
1159.65218073±0.00000028	HANNEKE	08	MRS		Single electron
1159.6521884 ±0.0000043	VANDYCK	87	MRS	−	Single electron
• • • We do not use the following data for averages, fits, limits, etc. • • •					
1159.65218046±0.00000018	MOHR	25	RVUE		2022 CODATA value
1159.65218128±0.00000018	TIESINGA	21	RVUE		2018 CODATA value
1159.65218091±0.00000026	MOHR	16	RVUE		2014 CODATA value
1159.65218076±0.00000027	MOHR	12	RVUE		2010 CODATA value

1159.65218111 ± 0.00000074	[2] MOHR	08	RVUE		2006 CODATA value
1159.65218085 ± 0.00000076	[3] ODOM	06	MRS	−	Single electron
1159.6521859 ± 0.0000038	MOHR	05	RVUE		2002 CODATA value
1159.6521869 ± 0.0000041	MOHR	99	RVUE		1998 CODATA value
1159.652193 ± 0.000010	COHEN	87	RVUE		1986 CODATA value
1159.6521879 ± 0.0000043	[4] VANDYCK	87	MRS	+	Single positron

[1] FAN 23 report the most accurate measurement of the electron magnetic moment. A one-electron quantum cyclotron is used. We do not propagate at the moment this measurement to the fine structure and other physical constants. When discrepancies in the independent determinations of alpha are resolved, the new measurement uncertainty of 0.13 ppt is available for precise tests for BSM physics.

[2] MOHR 08 average is dominated by ODOM 06.

[3] Superseded by HANNEKE 08 per private communication with Gerald Gabrielse.

[4] This VANDYCK 87 reault is for a positron. We do not take it into account for the average to avoid the assumption of CPT invariance.

$(g_{e^+} - g_{e^-}) \,/\, g_{\text{average}}$

A test of *CPT* invariance.

VALUE (units 10^{-12})	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
− 0.5± 2.1		[1] VANDYCK	87	MRS	Penning trap
• • • We do not use the following data for averages, fits, limits, etc. • • •					
< 12	95	[2] VASSERMAN	87	CNTR	Assumes $m_{e^+} = m_{e^-}$
22 ±64		SCHWINBERG	81	MRS	Penning trap

[1] VANDYCK 87 measured $(g_-/g_+)-1$ and we converted it.

[2] VASSERMAN 87 measured $(g_+ - g_-)/(g-2)$. We multiplied by $(g-2)/g = 1.2 \times 10^{-3}$.

e ELECTRIC DIPOLE MOMENT (d)

A nonzero value is forbidden by both *T* invariance and *P* invariance.

VALUE (10^{-28} *e* cm)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
< 0.041	90	[1] ROUSSY	23	ESR	electrons in intramolecular electric field
• • • We do not use the following data for averages, fits, limits, etc. • • •					
< 0.11	90	[2] ANDREEV	18	CNTR	ThO molecules
< 1.3	90	[3] CAIRNCROSS	17	ESR	^{180}Hf^{19}F molecules
− 5570 ± 7980 ±120		KIM	15	CNTR	$Gd_3Ga_5O_{12}$ molecules
< 0.87	90	[4] BARON	14	CNTR	ThO molecules
< 6050	90	[5] ECKEL	12	CNTR	$Eu_{0.5}Ba_{0.5}TiO_3$ molecules
< 10.5	90	[6] HUDSON	11	NMR	YbF molecules
6.9 ± 7.4		REGAN	02	MRS	^{205}Tl beams
18 ± 12 ± 10		[7] COMMINS	94	MRS	^{205}Tl beams
− 27 ± 83		[7] ABDULLAH	90	MRS	^{205}Tl beams
− 1400 ± 2400		CHO	89	NMR	TlF molecules

$-150 \pm 550 \pm 150$		MURTHY	89		Cs, no B field
-5000 ± 11000		LAMOREAUX	87	NMR	^{199}Hg
19000 ± 34000	90	SANDARS	75	MRS	Thallium
7000 ± 22000	90	PLAYER	70	MRS	Xenon
< 30000	90	WEISSKOPF	68	MRS	Cesium

[1] ROUSSY 23 gives a measurement corresponding to this limit as $(-1.3 \pm 2.0 \pm 0.6) \times 10^{-30}$ *e*cm.

[2] ANDREEV 18 gives a measurement corresponding to this limit as $(4.3 \pm 3.1 \pm 2.6) \times 10^{-30}$ *e*cm.

[3] CAIRNCROSS 17 gives a measurement corresponding to this limit as $(0.09 \pm 0.77 \pm 0.17) \times 10^{-28}$ *e*cm.

[4] BARON 14 gives a measurement corresponding to this limit as $(-0.21 \pm 0.37 \pm 0.25) \times 10^{-28}$ *e*cm.

[5] ECKEL 12 gives a measurement corresponding to this limit as $(-1.07 \pm 3.06 \pm 1.74) \times 10^{-25}$ *e*cm.

[6] HUDSON 11 gives a measurement corresponding to this limit as $(-2.4 \pm 5.7 \pm 1.5) \times 10^{-28}$ *e*cm.

[7] ABDULLAH 90, COMMINS 94, and REGAN 02 use the relativistic enhancement of a valence electron's electric dipole moment in a high-Z atom.

e^- MEAN LIFE / BRANCHING FRACTION

A test of charge conservation. See the "Note on Testing Charge Conservation and the Pauli Exclusion Principle" following this section in our 1992 edition (Physical Review **D45** S1 (1992), p. VI.10).

Most of these experiments are one of three kinds: Attempts to observe (a) the 255.5 keV gamma ray produced in $e^- \rightarrow \nu_e \gamma$, (b) the (K) shell x ray produced when an electron decays without additional energy deposit, e.g., $e^- \rightarrow \nu_e \overline{\nu}_e \nu_e$ ("disappearance" experiments), and (c) nuclear de-excitation gamma rays after the electron disappears from an atomic shell and the nucleus is left in an excited state. The last can include both weak boson and photon mediating processes. We use the best $e^- \rightarrow \nu_e \gamma$ limit for the Summary Tables.

Note that we use the mean life rather than the half life, which is often reported.

$e \rightarrow \nu_e \gamma$ and astrophysical limits

VALUE (yr)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
$\mathbf{>6.6 \times 10^{28}}$	90	AGOSTINI	15B	BORX	$e^- \rightarrow \nu\gamma$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$>5.4 \times 10^{25}$	90	[1] AGOSTINI	24A	HPGE	$e^- \rightarrow \nu\gamma$, ^{76}Ge detector
$>1.22 \times 10^{26}$	68	[2] KLAPDOR-K...	07	CNTR	$e^- \rightarrow \nu\gamma$
$>4.6 \times 10^{26}$	90	BACK	02	BORX	$e^- \rightarrow \nu\gamma$
$>3.4 \times 10^{26}$	68	BELLI	00B	DAMA	$e^- \rightarrow \nu\gamma$, liquid Xe
$>3.7 \times 10^{25}$	68	AHARONOV	95B	CNTR	$e^- \rightarrow \nu\gamma$
$>2.35 \times 10^{25}$	68	BALYSH	93	CNTR	$e^- \rightarrow \nu\gamma$, ^{76}Ge detector
$>1.5 \times 10^{25}$	68	AVIGNONE	86	CNTR	$e^- \rightarrow \nu\gamma$
$>1 \times 10^{39}$		[3] ORITO	85	ASTR	Astrophysical argument
$>3 \times 10^{23}$	68	BELLOTTI	83B	CNTR	$e^- \rightarrow \nu\gamma$

[1] AGOSTINI 24A search for coincident photons from the direct *e*-decay and from residual X-ray or Auger-*e* transitions.

[2] The authors of A. Derbin et al, arXiv:0704.2047v1 argue that this limit is overestimated by at least a factor of 5.

[3] ORITO 85 assumes that electromagnetic forces extend out to large enough distances and that the age of our galaxy is 10^{10} years.

Disappearance and nuclear-de-excitation experiments

VALUE (yr)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
$>3.2 \times 10^{25}$	90	[1] ARNQUIST	24B	HPGE	Ge K-shell disappearance
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$>1.2 \times 10^{24}$	90	ABGRALL	17	HPGE	Ge K-shell disappearance
$>4.2 \times 10^{24}$	68	BELLI	99	DAMA	Iodine L-shell disappearance
$>6.4 \times 10^{24}$	68	[2] BELLI	99B	DAMA	De-excitation of ^{129}Xe
$>2.4 \times 10^{23}$	90	[3] BELLI	99D	DAMA	De-excitation of ^{127}I (in NaI)
$>4.3 \times 10^{23}$	68	AHARONOV	95B	CNTR	Ge K-shell disappearance
$>2.7 \times 10^{23}$	68	REUSSER	91	CNTR	Ge K-shell disappearance
$>2 \times 10^{22}$	68	BELLOTTI	83B	CNTR	Ge K-shell disappearance

[1] ARNQUIST 24B limit on charge nonconserving e^- capture in 37.5 kg high-purity Ge implies limit on $e \to \nu\overline{\nu}\nu$ or more generally $e \to$ invisible.

[2] BELLI 99B limit on charge nonconserving e^- capture involving excitation of the 236.1 keV nuclear state of ^{129}Xe. The 90% CL limit is $>3.7 \times 10^{24}$ yr. Less stringent limits for other states are also given.

[3] BELLI 99D limit on charge nonconserving e^- capture involving excitation of the 57.6 keV nuclear state of ^{127}I. Less stringent limits for the other states and for the state of ^{23}Na are also given.

LIMITS ON LEPTON-FLAVOR VIOLATION IN PRODUCTION

Forbidden by lepton family number conservation.

This section was added for the 2008 edition of this *Review* and is not complete. For a list of further measurements see references in the papers listed below.

$\sigma(e^+e^- \to e^\pm\tau^\mp)$ / $\sigma(e^+e^- \to \mu^+\mu^-)$

VALUE	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
$<8.9 \times 10^{-6}$	95	AUBERT	07P	BABR	e^+e^- at $E_{\mathrm{cm}} = 10.58$ GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$<1.8 \times 10^{-3}$	95	GOMEZ-CAD...	91	MRK2	e^+e^- at $E_{\mathrm{cm}} = 29$ GeV

$\sigma(e^+e^- \to \mu^\pm\tau^\mp)$ / $\sigma(e^+e^- \to \mu^+\mu^-)$

VALUE	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
$<4.0 \times 10^{-6}$	95	AUBERT	07P	BABR	e^+e^- at $E_{\mathrm{cm}} = 10.58$ GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$<6.1 \times 10^{-3}$	95	GOMEZ-CAD...	91	MRK2	e^+e^- at $E_{\mathrm{cm}} = 29$ GeV

e REFERENCES

MOHR	25	RMP 97 025002	P.J. Mohr *et al.*	(NIST)
AGOSTINI	24A	EPJ C84 940	M. Agostini *et al.*	(GERDA Collab.)
ARNQUIST	24B	NATP 20 1078	I.J. Arnquist *et al.*	(MAJORANA Collab.)
FAN	23	PRL 130 071801	X. Fan *et al.*	(HARV, NWES)
ROUSSY	23	SCI 381 46	T.S. Roussy *et al.*	(COLO)
TIESINGA	21	RMP 93 025010	E. Tiesinga *et al.*	(NIST)
ANDREEV	18	NAT 562 355	V. Andreev *et al.*	(ACME Collab.)
ABGRALL	17	PRL 118 161801	N. Abgrall *et al.*	(MAJORANA Collab.)
CAIRNCROSS	17	PRL 119 153001	W.B. Cairncross *et al.*	(NIST,COLO)
MOHR	16	RMP 88 035009	P.J. Mohr, D.B. Newell, B.N. Taylor	(NIST)
AGOSTINI	15B	PRL 115 231802	M. Agostini *et al.*	(Borexino Collab.)
KIM	15	PR D91 102004	Y.J. Kim *et al.*	(IND, YALE, LANL)
BARON	14	SCI 343 269	J. Baron *et al.*	(ACME Collab.)
DOLGOV	14	PL B732 244	A.D. Dolgov, V.A. Novikov	
ECKEL	12	PRL 109 193003	S. Eckel, A.O. Sushkov, S.K. Lamoreaux	(YALE)
MOHR	12	RMP 84 1527	P.J. Mohr, B.N. Taylor, D.B. Newell	(NIST)
PDG	12	PR D86 010001	J. Beringer *et al.*	(PDG Collab.)
HUDSON	11	NAT 473 493	J.J. Hadson *et al.*	(LOIC)
HANNEKE	08	PRL 100 120801	D. Hanneke, S. Fogwell, G. Gabrielse	(HARV)
MOHR	08	RMP 80 633	P.J. Mohr, B.N. Taylor, D.B. Newell	(NIST)
AUBERT	07P	PR D75 031103	B. Aubert *et al.*	(BABAR Collab.)
KLAPDOR-K...	07	PL B644 109	H.V. Klapdor-Kleingrothaus, I.V. Krivosheina, I.V. Titkova	
ODOM	06	PRL 97 030801	B. Odom *et al.*	(HARV)
MOHR	05	RMP 77 1	P.J. Mohr, B.N. Taylor	(NIST)
BACK	02	PL B525 29	H.O. Back *et al.*	(Borexino/SASSO Collab.)
BEIER	02	PRL 88 011603	T. Beier *et al.*	
REGAN	02	PRL 88 071805	B.C. Regan *et al.*	
BELLI	00B	PR D61 117301	P. Belli *et al.*	(DAMA Collab.)
BELLI	99	PL B460 236	P. Belli *et al.*	(DAMA Collab.)
BELLI	99B	PL B465 315	P. Belli *et al.*	(DAMA Collab.)
BELLI	99D	PR C60 065501	P. Belli *et al.*	(DAMA Collab.)
MOHR	99	JPCRD 28 1713	P.J. Mohr, B.N. Taylor	(NIST)
Also		RMP 72 351	P.J. Mohr, B.N. Taylor	(NIST)
AHARONOV	95B	PR D52 3785	Y. Aharonov *et al.*	(SCUC, PNL, ZARA+)
Also		PL B353 168	Y. Aharonov *et al.*	(SCUC, PNL, ZARA+)
FARNHAM	95	PRL 75 3598	D.L. Farnham, R.S. van Dyck, P.B. Schwinberg	(WASH)
SCHAEFER	95	PR A51 838	A. Schaefer, J. Reinhardt	(FRAN)
COMMINS	94	PR A50 2960	E.D. Commins *et al.*	
BALYSH	93	PL B298 278	A. Balysh *et al.*	(KIAE, MPIK, SASSO)
FEE	93	PR A48 192	M.S. Fee *et al.*	
HUGHES	92	PRL 69 578	R.J. Hughes, B.I. Deutch	(LANL, AARH)
MUELLER	92	PRL 69 3432	B. Muller, M.H. Thoma	(DUKE)
PDG	92	PR D45 S1	K. Hikasa *et al.*	(KEK, LBL, BOST+)
GOMEZ-CAD...	91	PRL 66 1007	J.J. Gomez-Cadenas *et al.*	(SLAC MARK-2 Collab.)
REUSSER	91	PL B255 143	D. Reusser *et al.*	(NEUC, CIT, PSI)
ABDULLAH	90	PRL 65 2347	K. Abdullah *et al.*	(LBL, UCB)
CHO	89	PRL 63 2559	D. Cho, K. Sangster, E.A. Hinds	(YALE)
MURTHY	89	PRL 63 965	S.A. Murthy *et al.*	(AMHT)
COHEN	87	RMP 59 1121	E.R. Cohen, B.N. Taylor	(RISC, NBS)
LAMOREAUX	87	PRL 59 2275	S.K. Lamoreaux *et al.*	(WASH)
VANDYCK	87	PRL 59 26	R.S. van Dyck, P.B. Schwinberg, H.G. Dehmelt	(WASH)
VASSERMAN	87	PL B198 302	I.B. Vasserman *et al.*	(NOVO)
Also		PL B187 172	I.B. Vasserman *et al.*	(NOVO)
AVIGNONE	86	PR D34 97	F.T. Avignone *et al.*	(PNL, SCUC)
ORITO	85	PRL 54 2457	S. Orito, M. Yoshimura	(TOKY, KEK)
CHU	84	PRL 52 1689	S. Chu, A.P. Mills, J.L. Hall	(BELL, NBS, COLO)
BELLOTTI	83B	PL 124B 435	E. Bellotti *et al.*	(MILA)
SCHWINBERG	81	PRL 47 1679	P.B. Schwinberg, R.S. van Dyck, H.G. Dehmelt	(WASH)
SANDARS	75	PR A11 473	P.G.H. Sandars, D.M. Sternheimer	(OXF, BNL)
COHEN	73	JPCRD 2 664	E.R. Cohen, B.N. Taylor	(RISC, NBS)
PLAYER	70	JP B3 1620	M.A. Player, P.G.H. Sandars	(OXF)
WEISSKOPF	68	PRL 21 1645	M.C. Weisskopf *et al.*	(BRAN)