$\boxed{\gamma}$

$I(J^{PC}) = 0,1(1^{--})$

γ MASS

For a review of the photon mass, see BYRNE 77.

VALUE (eV)	*CL%*	*DOCUMENT ID*	*TECN*	*COMMENT*
$< 1 \times 10^{-18}$		[1] RYUTOV 07		MHD of solar wind
• • • We do not use the following data for averages, fits, limits, etc. • • •				
$< 1 \times 10^{-26}$		[2] ADELBERGER 07A		Galactic field existence if Higgs mass
$< 1.4 \times 10^{-7}$		ACCIOLY 04		Dispersion of GHz radio waves by sun
$< 2 \times 10^{-16}$		FULLEKRUG 04		Speed of 5-50 Hz radiation in atmosphere
$< 7 \times 10^{-19}$		[3] LUO 03		Modulation torsion balance
$< 1 \times 10^{-17}$		[4] LAKES 98		Torque on toroid balance
$< 6 \times 10^{-17}$		[5] RYUTOV 97		MHD of solar wind
$< 9 \times 10^{-16}$	90	[6] FISCHBACH 94		Earth magnetic field
$<(4.73 \pm 0.45) \times 10^{-12}$		[7] CHERNIKOV 92	SQID	Ampere-law null test
$<(9.0 \pm 8.1) \times 10^{-10}$		[8] RYAN 85		Coulomb-law null test
$< 3 \times 10^{-27}$		[9] CHIBISOV 76		Galactic magnetic field
$< 6 \times 10^{-16}$	99.7	DAVIS 75		Jupiter magnetic field
$< 7.3 \times 10^{-16}$		HOLLWEG 74		Alfven waves
$< 6 \times 10^{-17}$		[10] FRANKEN 71		Low freq. res. cir.
$< 1 \times 10^{-14}$		WILLIAMS 71	CNTR	Tests Gauss law
$< 2.3 \times 10^{-15}$		GOLDHABER 68		Satellite data
$< 6 \times 10^{-15}$		[10] PATEL 65		Satellite data
$< 6 \times 10^{-15}$		GINTSBURG 64		Satellite data

[1] RYUTOV 07 extends the method of RYUTOV 97 to the radius of Pluto's orbit.

[2] When trying to measure m one must distinguish between measurements performed on large and small scales. If the photon acquires mass by the Higgs mechanism, the large-scale behavior of the photon might be effectively Maxwellian. If, on the other hand, one postulates the Proca regime for all scales, the very existence of the galactic field implies $m < 10^{-26}$ eV, as correctly calculated by YAMAGUCHI 59 and CHIBISOV 76.

[3] LUO 03 determine a limit on $\mu^2 A < 1.1 \times 10^{-11}$ T m/m^2 (with μ^{-1}=characteristic length for photon mass; A=ambient vector potential) — similar to the LAKES 98 technique. Unlike LAKES 98 who used static, the authors used dynamic torsion balance. Assuming A to be 10^{12} T m, they obtain $\mu < 1.2 \times 10^{-51}$ g, equivalent to 6.7×10^{-19} eV. The rotating modified Cavendish balance removes dependence on the direction of A. GOLDHABER 03 argue that because plasma current effects are neglected, the LUO 03 limit does not provide the best available limit on $\mu^2 A$ nor a reliable limit at all on μ. The reason is that the A associated with cluster magnetic fields could become arbitrarily small in plasma voids, whose existence would be compatible with present knowledge. LUO 03B reply that fields of distant clusters are not accurately mapped, but assert that a zero A is unlikely given what we know about the magnetic field in our galaxy.

[4] LAKES 98 reports limits on torque on a toroid Cavendish balance, obtaining a limit on $\mu^2 A < 2 \times 10^{-9}$ Tm/m^2 via the Maxwell-Proca equations, where μ^{-1} is the characteristic length associated with the photon mass and A is the ambient vector potential in the Lorentz gauge. Assuming $A \approx 1 \times 10^{12}$ Tm due to cluster fields he obtains

$\mu^{-1} > 2 \times 10^{10}$ m, corresponding to $\mu < 1 \times 10^{-17}$ eV. A more conservative limit, using $A \approx (1\ \mu\text{G}) \times (600\ \text{pc})$ based on the galactic field, is $\mu^{-1} > 1 \times 10^{9}$ m or $\mu < 2 \times 10^{-16}$ eV.

[5] RYUTOV 97 uses a magnetohydrodynamics argument concerning survival of the Sun's field to the radius of the Earth's orbit. "To reconcile observations to theory, one has to reduce [the photon mass] by approximately an order of magnitude compared with" DAVIS 75.

[6] FISCHBACH 94 report $< 8 \times 10^{-16}$ with unknown CL. We report Bayesian CL used elsewhere in these Listings and described in the Statistics section.

[7] CHERNIKOV 92 measures the photon mass at 1.24 K, following a theoretical suggestion that electromagnetic gauge invariance might break down at some low critical temperature. See the erratum for a correction, included here, to the published result.

[8] RYAN 85 measures the photon mass at 1.36 K (see the footnote to CHERNIKOV 92).

[9] CHIBISOV 76 depends in critical way on assumptions such as applicability of virial theorem. Some of the arguments given only in unpublished references.

[10] See criticism questioning the validity of these results in GOLDHABER 71, PARK 71 and KROLL 71. See also review GOLDHABER 71B.

γ CHARGE

VALUE (*e*)	*DOCUMENT ID*		*TECN*	*COMMENT*
$<5 \times 10^{-30}$	[11] RAFFELT	94	TOF	Pulsar $f_1 - f_2$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
$<8.5 \times 10^{-17}$	[12] SEMERTZIDIS	03		Laser light deflection in B-field
$<2 \times 10^{-28}$	[13] COCCONI	92		VLBA radio telescope resolution
$<2 \times 10^{-32}$	COCCONI	88	TOF	Pulsar $f_1 - f_2$ TOF

[11] RAFFELT 94 notes that COCCONI 88 neglects the fact that the time delay due to dispersion by free electrons in the interstellar medium has the same photon energy dependence as that due to bending of a charged photon in the magnetic field. His limit is based on the assumption that the entire observed dispersion is due to photon charge. It is a factor of 200 less stringent than the COCCONI 88 limit.

[12] SEMERTZIDIS 03 reports the first laboratory limit on the photon charge in the last 30 years. Straightforward improvements in the apparatus could attain a sensitivity of 10^{-20} e.

[13] See COCCONI 92 for less stringent limits in other frequency ranges. Also see RAFFELT 94 note.

γ REFERENCES

ADELBERGER	07A	PRL 98 010402	E. Adelberger, G. Dvali, A. Gruzinov	(WASH, NYU)
RYUTOV	07	PPCF 49 B429	D.D. Ryutov	(LLNL)
ACCIOLY	04	PR D69 107501	A. Accioly, R. Paszko	
FULLEKRUG	04	PRL 93 043901	M. Fullekrug	
GOLDHABER	03	PRL 91 149101	A.S. Goldhaber, M.M. Nieto	
LUO	03	PRL 90 081801	J. Luo *et al.*	
LUO	03B	PRL 91 149102	J. Luo *et al.*	
SEMERTZIDIS	03	PR D67 017701	Y.K. Semertzidis, G.T. Danby, D.M. Lazarus	
LAKES	98	PRL 80 1826	R. Lakes	(WISC)
RYUTOV	97	PPCF 39 A73	D.D. Ryutov	(LLNL)
FISCHBACH	94	PRL 73 514	E. Fischbach *et al.*	(PURD, JHU+)
RAFFELT	94	PR D50 7729	G. Raffelt	(MPIM)
CHERNIKOV	92	PRL 68 3383	M.A. Chernikov *et al.*	(ETH)
Also		PRL 69 2999 (erratum)	M.A. Chernikov *et al.*	(ETH)
COCCONI	92	AJP 60 750	G. Cocconi	(CERN)
COCCONI	88	PL B206 705	G. Cocconi	(CERN)
RYAN	85	PR D32 802	J.J. Ryan, F. Accetta, R.H. Austin	(PRIN)
BYRNE	77	Ast.Sp.Sci. 46 115	J. Byrne	(LOIC)
CHIBISOV	76	SPU 19 624 Translated from UFN 119 551.	G.V. Chibisov	(LEBD)

DAVIS	75	PRL 35 1402	L. Davis, A.S. Goldhaber, M.M. Nieto	(CIT, STON+)
HOLLWEG	74	PRL 32 961	J.V. Hollweg	(NCAR)
FRANKEN	71	PRL 26 115	P.A. Franken, G.W. Ampulski	(MICH)
GOLDHABER	71	PRL 26 1390	A.S. Goldhaber, M.M. Nieto	(STON, BOHR, UCSB)
GOLDHABER	71B	RMP 43 277	A.S. Goldhaber, M.M. Nieto	(STON, BOHR, UCSB)
KROLL	71	PRL 26 1395	N.M. Kroll	(SLAC)
PARK	71	PRL 26 1393	D. Park, E.R. Williams	(WILC)
WILLIAMS	71	PRL 26 721	E.R. Williams, J.E. Faller, H.A. Hill	(WESL)
GOLDHABER	68	PRL 21 567	A.S. Goldhaber, M.M. Nieto	(STON)
PATEL	65	PL 14 105	V.L. Patel	(DUKE)
GINTSBURG	64	Sov. Astr. AJ7 536	M.A. Gintsburg	(ASCI)
YAMAGUCHI	59	PTPS 11 37	Y. Yamaguchi	