γ

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

γ MASS

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

VALUE (eV)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
$< 6 \times 10^{-17}$		[1] RYUTOV	97		MHD of solar wind
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$< 7 \times 10^{-19}$		[2] LUO	03		Modulation torsion balance
$< 1 \times 10^{-17}$		[3] LAKES	98		Torque on toroid balance
$< 9 \times 10^{-16}$	90	[4] FISCHBACH	94		Earth magnetic field
$<(4.73\pm0.45) \times 10^{-12}$		[5] CHERNIKOV	92	SQID	Ampere-law null test
$<(9.0\ \pm8.1\ ) \times 10^{-10}$		[6] RYAN	85		Coulomb-law null test
$< 3 \times 10^{-27}$		[7] 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
$< 6 \times 10^{-17}$		[8] 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
$< 6 \times 10^{-15}$		[8] PATEL	65		Satellite data
$< 6 \times 10^{-15}$		GINTSBURG	64		Satellite data

[1] 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.

[2] LUO 03 determine a limit on $\mu^2 \boldsymbol{A} < 1.1 \times 10^{-11}$ T m/m^2 (with μ^{-1}=characteristic length for photon mass; $\boldsymbol{A}$=ambient vector potential) — similar to the LAKES 98 technique. Unlike LAKES 98 who used static, the authors used dynamic torsion balance. Assuming $\boldsymbol{A}$ 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 $\boldsymbol{A}$. GOLDHABER 03 argue that because plasma current effects are neglected, the LUO 03 limit does not provide the best available limit on $\mu^2 \boldsymbol{A}$ nor a reliable limit at all on μ. The reason is that the $\boldsymbol{A}$ 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 $\boldsymbol{A}$ is unlikely given what we know about the magnetic field in our galaxy.

[3] LAKES 98 reports limits on torque on a toroid Cavendish balance, obtaining a limit on $\mu^2\boldsymbol{A} < 2 \times 10^{-9}$ Tm/m^2 via the Maxwell-Proca equations, where μ^{-1} is the characteristic length associated with the photon mass and $\boldsymbol{A}$ is the ambient vector potential in the Lorentz gauge. Assuming $\boldsymbol{A} \approx 1 \times 10^{12}$ 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 $\boldsymbol{A} \approx (1\ \mu\text{G})\times(600\ \text{pc})$ based on the galactic field, is $\mu^{-1} > 1 \times 10^9$ m or $\mu < 2 \times 10^{-16}$ eV.

[4] 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.

[5] 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.

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

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

[8] 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*
$<5 \times 10^{-30}$	[9] RAFFELT	94	TOF	Pulsar $f_1 - f_2$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
$<8.5 \times 10^{-17}$	[10] SEMERTZIDIS	03		Laser light deflection in B-field
$<2 \times 10^{-28}$	[11] COCCONI	92		VLBA radio telescope resolution
$<2 \times 10^{-32}$	COCCONI	88	TOF	Pulsar $f_1 - f_2$ TOF

[9] 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.

[10] 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.

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

γ REFERENCES

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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	92B	PRL 69 2999 (erratum)	M.A. Chernikov *et al.*	(ETH)
COCCONI	92	AJP 60 750	G. Cocconi	(CERN)
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