Magnetic Monopole Searches

See the related review(s):

Magnetic Monopoles

Monopole Production Cross Section — Accelerator Searches

X-SECT (cm^2)	MASS (GeV)	CHG (g)	ENERGY (GeV)	BEAM		DOCUMENT ID		TECN
$<2.5\text{E}-37$	200–6000	1	13000	$p p$	[1]	ACHARYA	17	INDU
$<2\text{E}-37$	200–6000	2	13000	$p p$	[1]	ACHARYA	17	INDU
$<4\text{E}-37$	200–5000	3	13000	$p p$	[1]	ACHARYA	17	INDU
$<1.5\text{E}-36$	400–4000	4	13000	$p p$	[1]	ACHARYA	17	INDU
$<7\text{E}-36$	1000–3000	5	13000	$p p$	[1]	ACHARYA	17	INDU
$<5\text{E}-40$	200–2500	0.5–2.0	8000	$p p$	[2]	AAD	16AB	ATLS
$<2\text{E}-37$	100–3500	1	8000	$p p$	[3]	ACHARYA	16	INDU
$<2\text{E}-37$	100–3500	2	8000	$p p$	[3]	ACHARYA	16	INDU
$<6\text{E}-37$	500–3000	3	8000	$p p$	[3]	ACHARYA	16	INDU
$<7\text{E}-36$	1000–2000	4	8000	$p p$	[3]	ACHARYA	16	INDU
$<1.6\text{E}-38$	200–1200	1	7000	$p p$	[4]	AAD	12CS	ATLS
$<5\text{E}-38$	45–102	1	206	$e^+ e^-$	[5]	ABBIENDI	08	OPAL
$<0.2\text{E}-36$	200–700	1	1960	$p \overline{p}$	[6]	ABULENCIA	06K	CNTR
$< 2.\text{E}-36$		1	300	$e^+ p$	[7,8]	AKTAS	05A	INDU
$< 0.2\ \text{E}-36$		2	300	$e^+ p$	[7,8]	AKTAS	05A	INDU
$< 0.09\text{E}-36$		3	300	$e^+ p$	[7,8]	AKTAS	05A	INDU
$< 0.05\text{E}-36$		≥ 6	300	$e^+ p$	[7,8]	AKTAS	05A	INDU
$< 2.\text{E}-36$		1	300	$e^+ p$	[7,9]	AKTAS	05A	INDU
$< 0.2\text{E}-36$		2	300	$e^+ p$	[7,9]	AKTAS	05A	INDU
$< 0.07\text{E}-36$		3	300	$e^+ p$	[7,9]	AKTAS	05A	INDU
$< 0.06\text{E}-36$		≥ 6	300	$e^+ p$	[7,9]	AKTAS	05A	INDU
$< 0.6\text{E}-36$	>265	1	1800	$p \overline{p}$	[10]	KALBFLEISCH	04	INDU
$< 0.2\text{E}-36$	>355	2	1800	$p \overline{p}$	[10]	KALBFLEISCH	04	INDU
$< 0.07\text{E}-36$	>410	3	1800	$p \overline{p}$	[10]	KALBFLEISCH	04	INDU
$< 0.2\text{E}-36$	>375	6	1800	$p \overline{p}$	[10]	KALBFLEISCH	04	INDU
$< 0.7\text{E}-36$	>295	1	1800	$p \overline{p}$	[11,12]	KALBFLEISCH	00	INDU
$< 7.8\text{E}-36$	>260	2	1800	$p \overline{p}$	[11,12]	KALBFLEISCH	00	INDU
$< 2.3\text{E}-36$	>325	3	1800	$p \overline{p}$	[11,13]	KALBFLEISCH	00	INDU
$< 0.11\text{E}-36$	>420	6	1800	$p \overline{p}$	[11,13]	KALBFLEISCH	00	INDU
$<0.65\text{E}-33$	<3.3	≥ 2	11A	^{197}Au	[14,15]	HE	97	
$<1.90\text{E}-33$	<8.1	≥ 2	160A	^{208}Pb	[14,15]	HE	97	
$<3.\text{E}-37$	<45.0	1.0	88–94	$e^+ e^-$		PINFOLD	93	PLAS
$<3.\text{E}-37$	<41.6	2.0	88–94	$e^+ e^-$		PINFOLD	93	PLAS
$<7.\text{E}-35$	<44.9	0.2–1.0	89–93	$e^+ e^-$		KINOSHITA	92	PLAS
$<2.\text{E}-34$	<850	≥ 0.5	1800	$p \overline{p}$		BERTANI	90	PLAS
$<1.2\text{E}-33$	<800	≥ 1	1800	$p \overline{p}$		PRICE	90	PLAS
$<1.\text{E}-37$	<29	1	50–61	$e^+ e^-$		KINOSHITA	89	PLAS
$<1.\text{E}-37$	<18	2	50–61	$e^+ e^-$		KINOSHITA	89	PLAS
$<1.\text{E}-38$	<17	<1	35	$e^+ e^-$		BRAUNSCH...	88B	CNTR
$<8.\text{E}-37$	<24	1	50–52	$e^+ e^-$		KINOSHITA	88	PLAS

<1.3E−35	<22	2	50–52	$e^+ e^-$		KINOSHITA	88	PLAS
<9.E−37	<4	<0.15	10.6	$e^+ e^-$		GENTILE	87	CLEO
<3.E−32	<800	≥ 1	1800	$p\overline{p}$		PRICE	87	PLAS
<3.E−38		<3	29	$e^+ e^-$		FRYBERGER	84	PLAS
<1.E−31		1,3	540	$p\overline{p}$		AUBERT	83B	PLAS
<4.E−38	<10	<6	34	$e^+ e^-$		MUSSET	83	PLAS
<8.E−36	<20		52	$p p$	[16]	DELL	82	CNTR
<9.E−37	<30	<3	29	$e^+ e^-$		KINOSHITA	82	PLAS
<1.E−37	<20	<24	63	$p p$		CARRIGAN	78	CNTR
<1.E−37	<30	<3	56	$p p$		HOFFMANN	78	PLAS
			62	$p p$	[16]	DELL	76	SPRK
<4.E−33			300	p	[16]	STEVENS	76B	SPRK
<1.E−40	<5	<2	70	p	[17]	ZRELOV	76	CNTR
<2.E−30			300	n	[16]	BURKE	75	OSPK
<1.E−38			8	ν	[18]	CARRIGAN	75	HLBC
<5.E−43	<12	<10	400	p		EBERHARD	75B	INDU
<2.E−36	<30	<3	60	$p p$		GIACOMELLI	75	PLAS
<5.E−42	<13	<24	400	p		CARRIGAN	74	CNTR
<6.E−42	<12	<24	300	p		CARRIGAN	73	CNTR
<2.E−36		1	0.001	γ	[17]	BARTLETT	72	CNTR
<1.E−41	<5		70	p		GUREVICH	72	EMUL
<1.E−40	<3	<2	28	p		AMALDI	63	EMUL
<2.E−40	<3	<2	30	p		PURCELL	63	CNTR
<1.E−35	<3	<4	28	p		FIDECARO	61	CNTR
<2.E−35	<1	1	6	p		BRADNER	59	EMUL

• • • We do not use the following data for averages, fits, limits, etc. • • •

<1.3E−40	200–4000	1	13000	$p p$	[19]	AAD	20G	ATLS
<5.6E−40	500–4000	2	13000	$p p$	[19]	AAD	20G	ATLS
	200–5000	2	13000	$p p$	[20]	ACHARYA	19B	INDU
	200–5000	1	13000	$p p$	[21]	ACHARYA	18A	INDU

[1] The search was sensitive to monopoles which had stopped in aluminium trapping volumes. Monopoles with spins 0 and 1/2 were considered; mass-dependent spin 1/2 monopole limits are quoted here.

[2] AAD 16AB model-independent 95% CL limits estimated using a fiducial region of approximately constant acceptance. Limits are mass-dependent.

[3] ACHARYA 16 limits at 95% CL estimated using a Drell-Yan-like production mechanism for scalar monopoles.

[4] AAD 12CS searched for monopoles as highly ionising objects. The cross section limits are based on an assumed Drell Yan-like production process for spin 1/2 monopoles. The limits are mass- and scenario-dependent.

[5] ABBIENDI 08 assume production of spin 1/2 monopoles with effective charge $g\beta$ (n=1), via $e^+ e^- \rightarrow \gamma^* \rightarrow M\overline{M}$, so that the cross section is proportional to $(1 + \cos^2\theta)$. There is no z information for such highly saturated tracks, so a parabolic track in the jet chamber is projected onto the xy plane. Charge per hit in the chamber produces a clean separation of signal and background.

[6] ABULENCIA 06K searches for high-ionizing signals in CDF central outer tracker and time-of-flight detector. For Drell-Yan $M\overline{M}$ production, the cross section limit implies $M > 360$ GeV at 95% CL.

[7] AKTAS 05A model-dependent limits as a function of monopole mass shown for arbitrary mass of 60 GeV. Based on search for stopped monopoles in the H1 Al beam pipe.

[8] AKTAS 05A limits with assumed elastic spin 0 monopole pair production.

[9] AKTAS 05A limits with assumed inelastic spin 1/2 monopole pair production.

[10] KALBFLEISCH 04 reports searches for stopped magnetic monopoles in Be, Al, and Pb samples obtained from discarded material from the upgrading of DØ and CDF. A large-aperture warm-bore cryogenic detector was used. The approach was an extension of the methods of KALBFLEISCH 00. Cross section results moderately model dependent; interpretation as a mass lower limit depends on possibly invalid perturbation expansion.

[11] KALBFLEISCH 00 used an induction method to search for stopped monopoles in pieces of the DØ (FNAL) beryllium beam pipe and in extensions to the drift chamber aluminum support cylinder. Results are model dependent.

[12] KALBFLEISCH 00 result is for aluminum.

[13] KALBFLEISCH 00 result is for beryllium.

[14] HE 97 used a lead target and barium phosphate glass detectors. Cross-section limits are well below those predicted via the Drell-Yan mechanism.

[15] This work has also been reinterpreted in the framework of monopole production via the thermal Schwinger process (GOULD 17); this gives rise to lower mass limits.

[16] Multiphoton events.

[17] Cherenkov radiation polarization.

[18] Re-examines CERN neutrino experiments.

[19] AAD 20G give limits for Drell-Yan production with spin-0 and spin-1/2 monopoles. The above limit is for spin = 0 at mass = 3 TeV.

[20] ACHARYA 19B limits both β-dependent and β-independent on monopoles with spins 0, 1/2, and 1 and with magnetic charges ranging from one to five times the Dirac charge in mass ranges between 200 GeV and 5000 GeV.

[21] ACHARYA 18A provide limits on monopoles with spins 0, 1/2, and 1 and with magnetic charges ranging from two to five times the Dirac charge.

Monopole Production — Other Accelerator Searches

MASS (GeV)	CHG (g)	SPIN	ENERGY (GeV)	BEAM	DOCUMENT ID		TECN
> 610	≥ 1	0	1800	$p\overline{p}$	[1] ABBOTT	98K	D0
> 870	≥ 1	1/2	1800	$p\overline{p}$	[1] ABBOTT	98K	D0
>1580	≥ 1	1	1800	$p\overline{p}$	[1] ABBOTT	98K	D0
> 510			88–94	e^+e^-	[2] ACCIARRI	95C	L3

[1] ABBOTT 98K search for heavy pointlike Dirac monopoles via central production of a pair of photons with high transverse energies.

[2] ACCIARRI 95C finds a limit B($Z \rightarrow \gamma\gamma\gamma$) $< 0.8 \times 10^{-5}$ (which is possible via a monopole loop) at 95% CL and sets the mass limit via a cross section model.

Monopole Flux — Cosmic Ray Searches

"Caty" in the charge column indicates a search for monopole-catalyzed nucleon decay.

FLUX ($\mathrm{cm}^{-2}\mathrm{sr}^{-1}\mathrm{s}^{-1}$)	MASS (GeV)	CHG (g)	COMMENTS ($\beta = v/c$)	EVTS	DOCUMENT ID		TECN
<1.5E−18		1	β >0.6	0	[1] ALBERT	17	ANTR
<2.5E−21		1	1E8< γ <1E13	0	[2] AAB	16	AUGE
<1.55E-18			β >0.51	0	[3] AARTSEN	16B	ICCB
<1E-17		Caty	1E-3< β <1E-2	0	[4] AARTSEN	14	ICCB
<3E-18		1	β >0.8	0	[5] ABBASI	13	ICCB
<1.3E-17		1	β >0.625	0	[6] ADRIAN-MAR...	12A	ANTR
<6E-28	<1E17	Caty	1E-5< β <0.04	0	[7] UENO	12	SKAM
<1E-19		**1**	**γ >1E10**	0	[8] DETRIXHE	11	ANIT
<3.8E-17		1	β >0.76	0	[5] ABBASI	10A	ICCB
<1.3E−15	1E4<M<5E13	1	β >0.05	0	[9] BALESTRA	08	PLAS

$<0.65E-15$	$>5E13$	1	$\beta>0.05$	0	[9] BALESTRA	08	PLAS
$<1E-18$		**1**	**$\gamma>1$ E8**	0	[8] HOGAN	08	RICE
$<1.4E-16$		**1**	**$1.1E-4<\beta<1$**	0	[10] AMBROSIO	02B	MCRO
$<3E-16$		Caty	$1.1E-4<\beta<5E-3$	0	[11] AMBROSIO	02C	MCRO
$<1.5E-15$		1	$5E-3<\beta<0.99$	0	[12] AMBROSIO	02D	MCRO
$<1E-15$		1	1.1×10^{-4}–0.1	0	[13] AMBROSIO	97	MCRO
$<5.6E-15$		1	$(0.18–3.0)E-3$	0	[14] AHLEN	94	MCRO
$<2.7E-15$		Caty	$\beta\sim1\times10^{-3}$	0	[15] BECKER-SZ...	94	IMB
$<8.7E-15$		1	$>2.E-3$	0	THRON	92	SOUD
$<4.4E-12$		1	all β	0	GARDNER	91	INDU
$<7.2E-13$		1	all β	0	HUBER	91	INDU
$<3.7E-15$	$>E12$	1	$\beta=1.E-4$	0	[16] ORITO	91	PLAS
$<3.2E-16$	$>E10$	1	$\beta>0.05$	0	[16] ORITO	91	PLAS
$<3.2E-16$	$>E10–E12$	2, 3		0	[16] ORITO	91	PLAS
$<3.8E-13$		1	all β	0	BERMON	90	INDU
$<5.E-16$		Caty	$\beta<1.E-3$	0	[15] BEZRUKOV	90	CHER
$<1.8E-14$		1	$\beta>1.1E-4$	0	[17] BUCKLAND	90	HEPT
$<1E-18$			$3.E-4<\beta<1.5E-3$	0	[18] GHOSH	90	MICA
$<7.2E-13$		1	all β	0	HUBER	90	INDU
$<5.E-12$	$>E7$	1	$3.E-4<\beta<5.E-3$	0	BARISH	87	CNTR
$<1.E-13$		Caty	$1.E-5<\beta<1$	0	[15] BARTELT	87	SOUD
$<1.E-10$		1	all β	0	EBISU	87	INDU
$<2.E-13$			$1.E-4<\beta<6.E-4$	0	MASEK	87	HEPT
$<2.E-14$			$4.E-5<\beta<2.E-4$	0	NAKAMURA	87	PLAS
$<2.E-14$			$1.E-3<\beta<1$	0	NAKAMURA	87	PLAS
$<5.E-14$			$9.E-4<\beta<1.E-2$	0	SHEPKO	87	CNTR
$<2.E-13$			$4.E-4<\beta<1$	0	TSUKAMOTO	87	CNTR
$<5.E-14$		1	all β	1	[19] CAPLIN	86	INDU
$<5.E-12$		1		0	CROMAR	86	INDU
$<1.E-13$		1	$7.E-4<\beta$	0	HARA	86	CNTR
$<7.E-11$		1	all β	0	INCANDELA	86	INDU
$<1.E-18$			$4.E-4<\beta<1.E-3$	0	[18] PRICE	86	MICA
$<5.E-12$		1		0	BERMON	85	INDU
$<6.E-12$		1		0	CAPLIN	85	INDU
$<6.E-10$		1		0	EBISU	85	INDU
$<3.E-15$		Caty	$5.E-5\leq\beta\leq1.E-3$	0	[15] KAJITA	85	KAMI
$<2.E-21$		Caty	$\beta<1.E-3$	0	[15,20] KAJITA	85	KAMI
$<3.E-15$		Caty	$1.E-3<\beta<1.E-1$	0	[15] PARK	85B	CNTR
$<5.E-12$		1	$1.E-4<\beta<1$	0	BATTISTONI	84	NUSX
$<7.E-12$		1		0	INCANDELA	84	INDU
$<7.E-13$		1	$3.E-4<\beta$	0	[17] KAJINO	84	CNTR
$<2.E-12$		1	$3.E-4<\beta<1.E-1$	0	KAJINO	84B	CNTR
$<6.E-13$		1	$5.E-4<\beta<1$	0	KAWAGOE	84	CNTR
$<2.E-14$			$1.E-3<\beta$	0	[15] KRISHNA...	84	CNTR
$<4.E-13$		1	$6.E-4<\beta<2.E-3$	0	LISS	84	CNTR
$<1.E-16$			$3.E-4<\beta<1.E-3$	0	[18] PRICE	84	MICA
$<1.E-13$		1	$1.E-4<\beta$	0	PRICE	84B	PLAS
$<4.E-13$		1	$6.E-4<\beta<2.E-3$	0	TARLE	84	CNTR
				7	[21] ANDERSON	83	EMUL
$<4.E-13$		1	$1.E-2<\beta<1.E-3$	0	BARTELT	83B	CNTR
$<1.E-12$		1	$7.E-3<\beta<1$	0	BARWICK	83	PLAS

<3.E−13		1	1.E−3 < β <4.E−1	0	BONARELLI	83	CNTR
<3.E−12		Caty	5.E−4 < β <5.E−2	0	[15] BOSETTI	83	CNTR
<4.E−11		1		0	CABRERA	83	INDU
<5.E−15		1	1.E−2 < β <1	0	DOKE	83	PLAS
<8.E−15		Caty	1.E−4 < β <1.E−1	0	[15] ERREDE	83	IMB
<5.E−12		1	1.E−4 < β <3.E−2	0	GROOM	83	CNTR
<2.E−12			6.E−4 < β <1	0	MASHIMO	83	CNTR
<1.E−13		1	β=3.E−3	0	ALEXEYEV	82	CNTR
<2.E−12		1	7.E−3 < β <6.E−1	0	BONARELLI	82	CNTR
6.E−10		1	all β	1	[22] CABRERA	82	INDU
<2.E−11			1.E−2 < β <1.E−1	0	MASHIMO	82	CNTR
<2.E−15			concentrator	0	BARTLETT	81	PLAS
<1.E−13	>1		1.E−3 < β	0	KINOSHITA	81B	PLAS
<5.E−11	<E17		3.E−4 < β <1.E−3	0	ULLMAN	81	CNTR
<2.E−11			concentrator	0	BARTLETT	78	PLAS
1.E−1	>200	2		1	[23] PRICE	75	PLAS
<2.E−13		>2		0	FLEISCHER	71	PLAS
<1.E−19		>2	obsidian, mica	0	FLEISCHER	69C	PLAS
<5.E−15	<15	<3	concentrator	0	CARITHERS	66	ELEC
<2.E−11		<1–3	concentrator	0	MALKUS	51	EMUL

[1] ALBERT 17 limits were estimated using a Cherenkov light in an array of optical modules under the Mediterranean Sea. The limits are for MM masses between 10^{10} and 10^{14} GeV. The limits are speed-dependent.

[2] AAB 16 search was made with a set of telescopes sampling the longitudinal profile of fluorescence light emitted by extensive air showers. Limits are speed dependent.

[3] AARTSEN 16B was based on a Cherenkov signature in an array of optical modules which were sunk in the Antarctic ice cap. Limits are speed-dependent.

[4] Beyond the monopole speed, the limits of AARTSEN 14 depend on the catalysis cross section (σ) which corresponds to the monopole radiating $\hat{l}$ times the light per track length compared to the Cherenkov light from a single electrically charged, relativistic particle. The values quoted here correspond to $\sigma = 1$ barn or $\hat{l} = 30$.

[5] ABBASI 13 and ABBASI 10A were based on a Cherenkov signature in an array of optical modules which were sunk in the Antarctic ice cap. Limits are speed-dependent.

[6] ADRIAN-MARTINEZ 12A measurements were based on a Cherenkov signature in an underwater telescope in the Western Mediterranean Sea. Limits are speed-dependent.

[7] The limits from UENO 12 depend on the monopole speed and are also sensitive to assumed values of monopole mass and the catalysis cross section.

[8] HOGAN 08 and DETRIXHE 11 limits on relativistic monopoles are based on nonobservation of radio Cherenkov signals at the South Pole. Limits are speed-dependent.

[9] BALESTRA 08 exposed of nuclear track detector modules totaling 400 m^2 for 4 years at the Chacaltaya Laboratory (5230 m) in search for intermediate-mass monopoles with $\beta >$ 0.05. The analysis is mainly based on three CR39 modules. For M $> 5 \times 10^{13}$ GeV there can be upward-going monopoles as well, hence the flux limit is half that obtained for less massive monopoles. Previous experiments (e.g. MACRO and OHYA (ORITO 91)) had set limits only for M $> 1 \times 10^9$ GeV.

[10] AMBROSIO 02B direct search final result for $m \geq 10^{17}$ GeV, based upon 4.2 to 9.5 years of running, depending upon the subsystem. Limit with CR39 track-etch detector extends the limit from β=4 $\times 10^{-5}$ (3.1×10^{-16} cm^{-2} sr^{-1} s^{-1}) to β= 1×10^{-4} (2.1×10^{-16} cm^{-2} sr^{-1} s^{-1}). Limit curve in paper is piecewise continuous due to different detection techniques for different β ranges.

[11] AMBROSIO 02C limit for catalysis of nucleon decay with catalysis cross section of $\approx$ 1 mb. The flux limit increases by $\sim$ 3 at the higher β limit, and increases to

1×10^{-14} cm^{-2} sr^{-1} s^{-1} if the catalysis cross section is 0.01 mb. Based upon 71193 hr of data with the streamer detector, with an acceptance of 4250 m^2 sr.

[12] AMBROSIO 02D result for "more than two years of data." Ionization search using several subsystems. Limit curve as a function of β not given. Included in AMBROSIO 02B.

[13] AMBROSIO 97 global MACRO 90%CL is 0.78×10^{-15} at β=1.1×10^{-4}, goes through a minimum at 0.61×10^{-15} near β=$(1.1–2.7) \times 10^{-3}$, then rises to 0.84×10^{-15} at β=0.1. The global limit in this region is below the Parker bound at 10^{-15}. Less stringent limits are established for $4 \times 10^{-5} < \beta < 1 \times 10^{-4}$. Limits set by various triggers and different subdetectors are given in the paper. All limits assume a catalysis cross section smaller than a few mb.

[14] AHLEN 94 limit for dyons extends down to β=0.9E−4 and a limit of 1.3E−14 extends to β = 0.8E−4. Also see comment by PRICE 94 and reply of BARISH 94. One loophole in the AHLEN 94 result is that in the case of monopoles catalyzing nucleon decay, relativistic particles could veto the events. See AMBROSIO 97 for additional results.

[15] Catalysis of nucleon decay; sensitive to assumed catalysis cross section.

[16] ORITO 91 limits are functions of velocity. Lowest limits are given here.

[17] Used DKMPR mechanism and Penning effect.

[18] Assumes monopole attaches fermion nucleus.

[19] Limit from combining data of CAPLIN 86, BERMON 85, INCANDELA 84, and CABRERA 83. For a discussion of controversy about CAPLIN 86 observed event, see GUY 87. Also see SCHOUTEN 87.

[20] Based on lack of high- energy solar neutrinos from catalysis in the sun.

[21] Anomalous long-range α (^{4}He) tracks.

[22] CABRERA 82 candidate event has single Dirac charge within ±5%.

[23] ALVAREZ 75, FLEISCHER 75, and FRIEDLANDER 75 explain as fragmenting nucleus. EBERHARD 75 and ROSS 76 discuss conflict with other experiments. HAGSTROM 77 reinterprets as antinucleus. PRICE 78 reassesses.

Monopole Flux — Astrophysics

FLUX ($cm^{-2}sr^{-1}s^{-1}$)	*MASS* (GeV)	*CHG* (g)	*COMMENTS* ($\beta = v/c$)	*DOCUMENT ID*		*TECN*
<1.3E−20			faint white dwarf	[1] FREESE	99	ASTR
<1.E−16	E17	1	galactic field	[2] ADAMS	93	COSM
<1.E−23			Jovian planets	[1] ARAFUNE	85	ASTR
<1.E−16	E15		solar trapping	BRACCI	85B	ASTR
<1.E−18		1		[1] HARVEY	84	COSM
<3.E−23			neutron stars	KOLB	84	ASTR
<7.E−22			pulsars	[1] FREESE	83B	ASTR
<1.E−18	<E18	1	intergalactic field	[1] REPHAELI	83	COSM
<1.E−23			neutron stars	[1] DIMOPOUL...	82	COSM
<5.E−22			neutron stars	[1] KOLB	82	COSM
<5.E−15	>E21		galactic halo	SALPETER	82	COSM
<1.E−12	E19	1	β=3.E−3	[3] TURNER	82	COSM
<1.E−16		1	galactic field	PARKER	70	COSM

[1] Catalysis of nucleon decay.

[2] ADAMS 93 limit based on "survival and growth of a small galactic seed field" is 10^{-16} $(m/10^{17}$ GeV) cm^{-2} s^{-1} sr^{-1}. Above 10^{17} GeV, limit 10^{-16} $(10^{17}$ GeV$/m)$ cm^{-2} s^{-1} sr^{-1} (from requirement that monopole density does not overclose the universe) is more stringent.

[3] Re-evaluates PARKER 70 limit for GUT monopoles.

Monopole Density — Matter Searches

DENSITY	CHG (g)	MATERIAL		DOCUMENT ID		TECN
<9.8E−5/gram	≥ 1	Polar rock		BENDTZ	13	INDU
<6.9E−6/gram	>1/3	Meteorites and other		JEON	95	INDU
<2.E−7/gram	>0.6	Fe ore	[1]	EBISU	87	INDU
<4.6E−6/gram	> 0.5	deep schist		KOVALIK	86	INDU
<1.6E−6/gram	> 0.5	manganese nodules	[2]	KOVALIK	86	INDU
<1.3E−6/gram	> 0.5	seawater		KOVALIK	86	INDU
>1.E+14/gram	>1/3	iron aerosols		MIKHAILOV	83	SPEC
<6.E−4/gram		air, seawater		CARRIGAN	76	CNTR
<5.E−1/gram	>0.04	11 materials		CABRERA	75	INDU
<2.E−4/gram	>0.05	moon rock		ROSS	73	INDU
<6.E−7/gram	<140	seawater		KOLM	71	CNTR
<1.E−2/gram	<120	manganese nodules		FLEISCHER	69	PLAS
<1.E−4/gram	>0	manganese		FLEISCHER	69B	PLAS
<2.E−3/gram	<1–3	magnetite, meteor		GOTO	63	EMUL
<2.E−2/gram		meteorite		PETUKHOV	63	CNTR

[1] Mass 1×10^{14}–1×10^{17} GeV.
[2] KOVALIK 86 examined 498 kg of schist from two sites which exhibited clear mineralogical evidence of having been buried at least 20 km deep and held below the Curie temperature.

Monopole Density — Astrophysics

DENSITY	CHG (g)	MATERIAL		DOCUMENT ID		TECN
<1.E−9/gram	1	sun, catalysis	[1]	ARAFUNE	83	COSM
<6.E−33/nucl	1	moon wake		SCHATTEN	83	ELEC
<2.E−28/nucl		earth heat		CARRIGAN	80	COSM
<2.E−4/prot		42cm absorption		BRODERICK	79	COSM
<2.E−13/m^3		moon wake		SCHATTEN	70	ELEC

[1] Catalysis of nucleon decay.

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