

Free Quark Searches

FREE QUARK SEARCHES

Quarks are fractionally charged particles, the constituents of hadrons, with charges $1/3\ e$ or $2/3\ e$. The charge of every known charged system is an integer multiple of $1/3\ e$. Quantum Chromodynamics predicts that quarks cannot be observed as freely propagating particles, being confined inside hadrons or deconfined in quark-gluon plasma (QGP). We observe the top quark decaying as still free, because its lifetime is too short to allow its hadronization. Experiments have produced no evidence for free propagating quarks.

Reviews can be found in Refs. 1–5.

References

1.

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Quark Production Cross Section — Accelerator Searches

<i>X-SECT</i> (cm ²)	<i>CHG</i> (<i>e</i> /3)	<i>MASS</i> (GeV)	<i>ENERGY</i> (GeV)	<i>BEAM</i>	<i>EVTS</i>	<i>DOCUMENT ID</i>	<i>TECN</i>
<1.7-2.3E-39	±2	100-600	7000	<i>p p</i>	0	¹ CHATRCHYAN 13AR CMS	
<14-5.4E-39	±1	100-600	7000	<i>p p</i>	0	¹ CHATRCHYAN 13AR CMS	
<1.3E-36	±2	45-84	130-172	<i>e⁺ e⁻</i>	0	ABREU	97D DLPH
<2.E-35	+2	250	1800	<i>p p̄</i>	0	² ABE	92J CDF
<1.E-35	+4	250	1800	<i>p p̄</i>	0	² ABE	92J CDF
<3.8E-28			14.5A	²⁸ Si-Pb	0	³ HE	91 PLAS
<3.2E-28			14.5A	²⁸ Si-Cu	0	³ HE	91 PLAS
<1.E-40	±1,2	<10		<i>p, ν, ν̄</i>	0	BERGSMA	84B CHRM
<1.E-36	±1,2	<9	200	<i>μ</i>	0	AUBERT	83C SPEC
<2.E-10	±2,4	1-3	200	<i>p</i>	0	⁴ BUSSIÈRE	80 CNTR
<5.E-38	+1,2	>5	300	<i>p</i>	0	^{5,6} STEVENSON	79 CNTR
<1.E-33	±1	<20	52	<i>p p</i>	0	BASILE	78 SPEC

$<9.E-39$	$\pm 1,2$	<6	400	p	0	⁵ ANTREASYAN	77	SPEC
$<8.E-35$	$+1,2$	<20	52	pp	0	⁷ FABJAN	75	CNTR
$<5.E-38$	$-1,2$	4–9	200	p	0	NASH	74	CNTR
$<1.E-32$	$+2,4$	4–24	52	pp	0	ALPER	73	SPEC
$<5.E-31$	$+1,2,4$	<12	300	p	0	LEIPUNER	73	CNTR
$<6.E-34$	$\pm 1,2$	<13	52	pp	0	BOTT	72	CNTR
$<1.E-36$	-4	4	70	p	0	ANTIPOV	71	CNTR
$<1.E-35$	$\pm 1,2$	2	28	p	0	⁸ ALLABY	69B	CNTR
$<4.E-37$	-2	<5	70	p	0	⁴ ANTIPOV	69	CNTR
$<3.E-37$	$-1,2$	2–5	70	p	0	⁸ ANTIPOV	69B	CNTR
$<1.E-35$	$+1,2$	<7	30	p	0	DORFAN	65	CNTR
$<2.E-35$	-2	$<2.5-5$	30	p	0	⁹ FRANZINI	65B	CNTR
$<5.E-35$	$+1,2$	<2.2	21	p	0	BINGHAM	64	HLBC
$<1.E-32$	$+1,2$	<4.0	28	p	0	BLUM	64	HBC
$<1.E-35$	$+1,2$	<2.5	31	p	0	⁹ HAGOPIAN	64	HBC
$<1.E-34$	$+1$	<2	28	p	0	LEIPUNER	64	CNTR
$<1.E-33$	$+1,2$	<2.4	24	p	0	MORRISON	64	HBC

¹ CHATRCHYAN 13AR limits assume pair-produced long-lived spin-1/2 particles neutral under $SU(3)_C$ and $SU(2)_L$.
² ABE 92J flux limits decrease as the mass increases from 50 to 500 GeV.
³ HE 91 limits are for charges of the form $N\pm 1/3$ from 23/3 to 38/3.
⁴ Hadronic or leptonic quarks.
⁵ Cross section cm^2/GeV^2 .
⁶ $3 \times 10^{-5} < \text{lifetime} < 1 \times 10^{-3} \text{ s}$.
⁷ Includes BOTT 72 results.
⁸ Assumes isotropic cm production.
⁹ Cross section inferred from flux.

Quark Differential Production Cross Section — Accelerator Searches

$X\text{-SECT}$ ($\text{cm}^2\text{sr}^{-1}\text{GeV}^{-1}$)	CHG $e/3$	$MASS$ (GeV)	$ENERGY$ (GeV)	$BEAM$	$EVTS$	$DOCUMENT\ ID$	$TECN$
$<4.E-36$	$-2,4$	1.5–6	70	p	0	BALDIN	76 CNTR
$<2.E-33$	± 4	5–20	52	pp	0	ALBROW	75 SPEC
$<5.E-34$	<7	7–15	44	pp	0	JOVANOVA...	75 CNTR
$<5.E-35$			20	γ	0	¹ GALIK	74 CNTR
$<9.E-35$	$-1,2$		200	p	0	NASH	74 CNTR
$<4.E-36$	-4	2.3–2.7	70	p	0	ANTIPOV	71 CNTR
$<3.E-35$	$\pm 1,2$	<2.7	27	p	0	ALLABY	69B CNTR
$<7.E-38$	$-1,2$	<2.5	70	p	0	ANTIPOV	69B CNTR

¹ Cross section in $\text{cm}^2/\text{sr}/\text{equivalent quanta}$.

Quark Flux — Accelerator Searches

The definition of FLUX depends on the experiment

- (a) is the ratio of measured free quarks to predicted free quarks if there is no “confinement.”
- (b) is the probability of fractional charge on nuclear fragments. Energy is in GeV/nucleon.
- (c) is the 90%CL upper limit on fractionally-charged particles produced per interaction.

- (d) is quarks per collision.
 (e) is inclusive quark-production cross-section ratio to $\sigma(e^+e^- \rightarrow \mu^+\mu^-)$.
 (f) is quark flux per charged particle.
 (g) is the flux per ν -event.
 (h) is quark yield per π^- yield.
 (i) is 2-body exclusive quark-production cross-section ratio to $\sigma(e^+e^- \rightarrow \mu^+\mu^-)$.

FLUX		CHG (e/3)	MASS (GeV)	ENRGY (GeV)	BEAM	EVTS	DOCUMENT ID	TECN
<1.6E-3	b	see note		200	32S-Pb	0	¹ HUENTRUP 96	PLAS
<6.2E-4	b	see note		10.6	32S-Pb	0	¹ HUENTRUP 96	PLAS
<0.94E-4	e	± 2	2-30	88-94	e^+e^-	0	AKERS 95R	OPAL
<1.7E-4	e	± 2	30-40	88-94	e^+e^-	0	AKERS 95R	OPAL
<3.6E-4	e	± 4	5-30	88-94	e^+e^-	0	AKERS 95R	OPAL
<1.9E-4	e	± 4	30-45	88-94	e^+e^-	0	AKERS 95R	OPAL
<2.E-3	e	+1	5-40	88-94	e^+e^-	0	² BUSKULIC 93C	ALEP
<6.E-4	e	+2	5-30	88-94	e^+e^-	0	² BUSKULIC 93C	ALEP
<1.2E-3	e	+4	15-40	88-94	e^+e^-	0	² BUSKULIC 93C	ALEP
<3.6E-4	i	+4	5.0-10.2	88-94	e^+e^-	0	BUSKULIC 93C	ALEP
<3.6E-4	i	+4	16.5-26.0	88-94	e^+e^-	0	BUSKULIC 93C	ALEP
<6.9E-4	i	+4	26.0-33.3	88-94	e^+e^-	0	BUSKULIC 93C	ALEP
<9.1E-4	i	+4	33.3-38.6	88-94	e^+e^-	0	BUSKULIC 93C	ALEP
<1.1E-3	i	+4	38.6-44.9	88-94	e^+e^-	0	BUSKULIC 93C	ALEP
<1.6E-4	b	see note	see note			0	³ CECCHINI 93	PLAS
	b	4,5,7,8		2.1A	¹⁶ O	0,2,0,6	⁴ GHOSH 92	EMUL
<6.4E-5	g	1			$\nu, \bar{\nu}$	1	⁵ BASILE 91	CNTR
<3.7E-5	g	2			$\nu, \bar{\nu}$	0	⁵ BASILE 91	CNTR
<3.9E-5	g	1			$\nu, \bar{\nu}$	1	⁶ BASILE 91	CNTR
<2.8E-5	g	2			$\nu, \bar{\nu}$	0	⁶ BASILE 91	CNTR
<1.9E-4	c			14.5A	²⁸ Si-Pb	0	⁷ HE 91	PLAS
<3.9E-4	c			14.5A	²⁸ Si-Cu	0	⁷ HE 91	PLAS
<1.E-9	c	$\pm 1,2,4$		14.5A	¹⁶ O-Ar	0	MATIS 91	MDRP
<5.1E-10	c	$\pm 1,2,4$		14.5A	¹⁶ O-Hg	0	MATIS 91	MDRP
<8.1E-9	c	$\pm 1,2,4$		14.5A	Si-Hg	0	MATIS 91	MDRP
<1.7E-6	c	$\pm 1,2,4$		60A	¹⁶ O-Hg	0	MATIS 91	MDRP
<3.5E-7	c	$\pm 1,2,4$		200A	¹⁶ O-Hg	0	MATIS 91	MDRP
<1.3E-6	c	$\pm 1,2,4$		200A	S-Hg	0	MATIS 91	MDRP
<5E-2	e	2	19-27	52-60	e^+e^-	0	ADACHI 90C	TOPZ
<5E-2	e	4	<24	52-60	e^+e^-	0	ADACHI 90C	TOPZ
<1.E-4	e	+2	<3.5	10	e^+e^-	0	BOWCOCK 89B	CLEO
<1.E-6	d	$\pm 1,2$		60	¹⁶ O-Hg	0	CALLOWAY 89	MDRP
<3.5E-7	d	$\pm 1,2$		200	¹⁶ O-Hg	0	CALLOWAY 89	MDRP
<1.3E-6	d	$\pm 1,2$		200	S-Hg	0	CALLOWAY 89	MDRP
<1.2E-10	d	± 1	1	800	p -Hg	0	MATIS 89	MDRP
<1.1E-10	d	± 2	1	800	p -Hg	0	MATIS 89	MDRP
<1.2E-10	d	± 1	1	800	p -N ₂	0	MATIS 89	MDRP
<7.7E-11	d	± 2	1	800	p -N ₂	0	MATIS 89	MDRP
<6.E-9	h	-5	0.9-2.3	12	p	0	NAKAMURA 89	SPEC
<5.E-5	g	1,2	<0.5		$\nu, \bar{\nu}d$	0	ALLASIA 88	BEBC

<3.E-4	b	See note	14.5	$^{16}\text{O-Pb}$	0	⁸	HOFFMANN	88	PLAS
<2.E-4	b	See note	200	$^{16}\text{O-Pb}$	0	⁹	HOFFMANN	88	PLAS
<8.E-5	b	19,20,22,23	200A				GERBIER	87	PLAS
<2.E-4	a	$\pm 1,2$	<300	320	$\bar{p}p$	0	LYONS	87	MLEV
<1.E-9	c	$\pm 1,2,4,5$	14.5	$^{16}\text{O-Hg}$	0		SHAW	87	MDRP
<3.E-3	d	-1,2,3,4,6	<5	2	Si-Si	0	¹⁰ ABACHI	86C	CNTR
<1.E-4	e	$\pm 1,2,4$	<4	10	e^+e^-	0	ALBRECHT	85G	ARG
<6.E-5	b	$\pm 1,2$	1	540	$p\bar{p}$	0	BANNER	85	UA2
<5.E-3	e	-4	1-8	29	e^+e^-	0	AIHARA	84	TPC
<1.E-2	e	$\pm 1,2$	1-13	29	e^+e^-	0	AIHARA	84B	TPC
<2.E-4	b	± 1		72	^{40}Ar	0	¹¹ BARWICK	84	CNTR
<1.E-4	e	± 2	<0.4	1.4	e^+e^-	0	BONDAR	84	OLYA
<5.E-1	e	$\pm 1,2$	<13	29	e^+e^-	0	GURYN	84	CNTR
<3.E-3	b	$\pm 1,2$	<2	540	$p\bar{p}$	0	BANNER	83	CNTR
<1.E-4	b	$\pm 1,2$		106	^{56}Fe	0	LINDGREN	83	CNTR
<3.E-3	b	$> \pm 0.1 $		74	^{40}Ar	0	¹¹ PRICE	83	PLAS
<1.E-2	e	$\pm 1,2$	<14	29	e^+e^-	0	MARINI	82B	CNTR
<8.E-2	e	$\pm 1,2$	<12	29	e^+e^-	0	ROSS	82	CNTR
<3.E-4	e	± 2	1.8-2	7	e^+e^-	0	WEISS	81	MRK2
<5.E-2	e	+1,2,4,5	2-12	27	e^+e^-	0	BARTEL	80	JADE
<2.E-5	g	1,2			ν	0	^{5,6} BASILE	80	CNTR
<3.E-10	f	$\pm 2,4$	1-3	200	p	0	¹² BOZZOLI	79	CNTR
<6.E-11	f	± 1	<21	52	pp	0	BASILE	78	SPEC
<5.E-3	g				ν_μ	0	BASILE	78B	CNTR
<2.E-9	f	± 1	<26	62	pp	0	BASILE	77	SPEC
<7.E-10	f	+1,2	<20	52	p	0	¹³ FABJAN	75	CNTR
		+1,2	>4.5		γ	0	^{5,6} GALIK	74	CNTR
		+1,2	>1.5	12	e^-	0	^{5,6} BELLAMY	68	CNTR
		+1,2	>0.9		γ	0	⁶ BATHOW	67	CNTR
		+1,2	>0.9	6	γ	0	⁶ FOSS	67	CNTR

¹ HUENTRUP 96 quote 95% CL limits for production of fragments with charge differing by as much as $\pm 1/3$ (in units of e) for charge $6 \leq Z \leq 10$.

² BUSKULIC 93C limits for inclusive quark production are more conservative if the ALEPH hadronic fragmentation function is assumed.

³ CECCHINI 93 limit at 90%CL for $23/3 \leq Z \leq 40/3$, for 16A GeV O, 14.5A Si, and 200A S incident on Cu target. Other limits are 2.3×10^{-4} for $17/3 \leq Z \leq 20/3$ and 1.2×10^{-4} for $20/3 \leq Z \leq 23/3$.

⁴ GHOSH 92 reports measurement of spallation fragment charge based on ionization in emulsion. Out of 650 measured tracks, 2 were consistent with charge $5e/3$, and 4 with $7e/3$.

⁵ Hadronic quark.

⁶ Leptonic quark.

⁷ HE 91 limits are for charges of the form $N \pm 1/3$ from $23/3$ to $38/3$, and correspond to cross-section limits of $380\mu\text{b}$ (Pb) and $320\mu\text{b}$ (Cu).

⁸ The limits apply to projectile fragment charges of 17, 19, 20, 22, 23 in units of $e/3$.

⁹ The limits apply to projectile fragment charges of 16, 17, 19, 20, 22, 23 in units of $e/3$.

¹⁰ Flux limits and mass range depend on charge.

¹¹ Bound to nuclei.

¹² Quark lifetimes $> 1 \times 10^{-8}$ s.

¹³ One candidate $m < 0.17$ GeV.

Quark Flux — Cosmic Ray Searches

Shielding values followed with an asterisk indicate altitude in km. Shielding values not followed with an asterisk indicate sea level in kg/cm^2 .

$FLUX$ ($\text{cm}^{-2}\text{sr}^{-1}\text{s}^{-1}$)	CHG ($e/3$)	$MASS$ (GeV)	$SHIELDING$	$DOCUMENT\ ID$	$TECN$
$< 6.2\text{E}-10$	± 2			1 ALEMANN0 22	DAMP
$< 1.\text{E}-8$	$\pm 1/6-1/10$			2 AGNESE 15	CDMS
$< 9.2\text{E}-15$	± 1		3800	3 AMBROSIO 00C	MCRO
$< 2.1\text{E}-15$	± 1			MORI 91	KAM2
$< 2.3\text{E}-15$	± 2			MORI 91	KAM2
$< 2.\text{E}-10$	$\pm 1, 2$		0.3	WADA 88	CNTR
	± 4		0.3	WADA 88	CNTR
	± 4		0.3	WADA 86	CNTR
$< 1.\text{E}-12$	$\pm 2, 3/2$		-70.	6 KAWAGOE 84B	PLAS
$< 9.\text{E}-10$	$\pm 1, 2$		0.3	WADA 84B	CNTR
$< 4.\text{E}-9$	± 4		0.3	WADA 84B	CNTR
$< 2.\text{E}-12$	$\pm 1, 2, 3$		-0.3 *	MASHIMO 83	CNTR
$< 3.\text{E}-10$	$\pm 1, 2$		0.3	MARINI 82	CNTR
$< 2.\text{E}-11$	$\pm 1, 2$			MASHIMO 82	CNTR
$< 8.\text{E}-10$	$\pm 1, 2$		0.3	6 NAPOLITANO 82	CNTR
				7 YOCK 78	CNTR
$< 1.\text{E}-9$				8 BRIATORE 76	ELEC
$< 2.\text{E}-11$	+1			9 HAZEN 75	CC
$< 2.\text{E}-10$	+1, 2			KRISOR 75	CNTR
$< 1.\text{E}-7$	+1, 2			9,10 CLARK 74B	CC
$< 3.\text{E}-10$	+1	>20		KIFUNE 74	CNTR
$< 8.\text{E}-11$	+1			9 ASHTON 73	CNTR
$< 2.\text{E}-8$	+1, 2			HICKS 73B	CNTR
$< 5.\text{E}-10$	+4		2.8 *	BEAUCHAMP 72	CNTR
$< 1.\text{E}-10$	+1, 2			9 BOHM 72B	CNTR
$< 1.\text{E}-10$	+1, 2		2.8 *	COX 72	ELEC
$< 3.\text{E}-10$	+2			CROUCH 72	CNTR
$< 3.\text{E}-8$			7	8 DARDO 72	CNTR
$< 4.\text{E}-9$	+1			9 EVANS 72	CC
$< 2.\text{E}-9$		>10		8 TONWAR 72	CNTR
$< 2.\text{E}-10$	+1		2.8 *	CHIN 71	CNTR
$< 3.\text{E}-10$	+1, 2			9 CLARK 71B	CC
$< 1.\text{E}-10$	+1, 2			9 HAZEN 71	CC
$< 5.\text{E}-10$	+1, 2		3.5 *	BOSIA 70	CNTR
	+1, 2	<6.5		9 CHU 70	HLBC
$< 2.\text{E}-9$	+1			FAISSNER 70B	CNTR
$< 2.\text{E}-10$	+1, 2		0.8 *	KRIDER 70	CNTR
$< 5.\text{E}-11$	+2			CAIRNS 69	CC
$< 8.\text{E}-10$	+1, 2	<10		FUKUSHIMA 69	CNTR
	+2			9,11 MCCUSKER 69	CC
$< 1.\text{E}-10$		>5	1.7, 3.6	8 BJORNBOE 68	CNTR
$< 1.\text{E}-8$	$\pm 1, 2, 4$		6.3, 2 *	6 BRIATORE 68	CNTR
$< 3.\text{E}-8$		>2		FRANZINI 68	CNTR
$< 9.\text{E}-11$	$\pm 1, 2$			GARMIRE 68	CNTR
$< 4.\text{E}-10$	± 1			HANAYAMA 68	CNTR
$< 3.\text{E}-8$		>15		KASHA 68	OSPK

$<2.E-10$	+2			KASHA	68B	CNTR
$<2.E-10$	+4			KASHA	68C	CNTR
$<2.E-10$	+2		6	BARTON	67	CNTR
$<2.E-7$	+4		0.008,0.5 *	BUHLER	67	CNTR
$<5.E-10$	1,2		0.008,0.5 *	BUHLER	67B	CNTR
$<4.E-10$	+1,2			GOMEZ	67	CNTR
$<2.E-9$	+2			KASHA	67	CNTR
$<2.E-10$	+2		220	BARTON	66	CNTR
$<2.E-9$	+1,2		0.5 *	BUHLER	66	CNTR
$<3.E-9$	+1,2			KASHA	66	CNTR
$<2.E-9$	+1,2			LAMB	66	CNTR
$<2.E-8$	+1,2	>7	2.8 *	DELISE	65	CNTR
$<5.E-8$	+2	>2.5	0.5 *	MASSAM	65	CNTR
$<2.E-8$	+1		2.5 *	BOWEN	64	CNTR
$<2.E-7$	+1		0.8	SUNYAR	64	CNTR

¹ ALEMANN0 22 uses data from the DAMPE satellite, with calorimetry and tracking to search for fractionally charged particles with $q = \pm 2/3e$ with a exposure time of 2.3×10^7 s.

² See AGNESE 15 Fig.6 for limits on vertical density as function of charge extending to $|q|/e < 1/10$.

³ AMBROSIO 00C limit is below 11×10^{-15} for $0.25 < q/e < 0.5$, and is changing rapidly near $q/e=2/3$, where it is 2×10^{-14} .

⁴ Distribution in celestial sphere was described as anisotropic.

⁵ With telescope axis at zenith angle 40° to the south.

⁶ Leptonic quarks.

⁷ Lifetime $> 10^{-8}$ s; charge $\pm 0.70, 0.68, 0.42$; and mass $> 4.4, 4.8$, and 20 GeV, respectively.

⁸ Time delayed air shower search.

⁹ Prompt air shower search.

¹⁰ Also $e/4$ and $e/6$ charges.

¹¹ No events in subsequent experiments.

Quark Density — Matter Searches

QUARKS/ NUCLEON	CHG (e/3)	MASS (GeV)	MATERIAL/METHOD	EVTS	DOCUMENT ID
$<1.17E-22$			silicone oil drops	0	¹ LEE 02
$<4.71E-22$			silicone oil drops	1	² HALYO 00
$<4.7E-21$	$\pm 1,2$		silicone oil drops	0	MAR 96
$<8.E-22$	+2		Si/infrared photoionization	0	PERERA 93
$<5.E-27$	$\pm 1,2$		sea water/levitation	0	HOMER 92
$<4.E-20$	$\pm 1,2$		meteorites/mag. levitation	0	JONES 89
$<1.E-19$	$\pm 1,2$		various/spectrometer	0	MILNER 87
$<5.E-22$	$\pm 1,2$		W/levitation	0	SMITH 87
$<3.E-20$	+1,2		org liq/droplet tower	0	VANPOLEN 87
$<6.E-20$	-1,2		org liq/droplet tower	0	VANPOLEN 87
$<3.E-21$	± 1		Hg drops-untreated	0	SAVAGE 86
$<3.E-22$	$\pm 1,2$		levitated niobium	0	SMITH 86
$<2.E-26$	$\pm 1,2$		^4He /levitation	0	SMITH 86B
$<2.E-20$	$> \pm 1$	0.2–250	niobium+tungs/ion	0	MILNER 85
$<1.E-21$	± 1		levitated niobium	0	SMITH 85
	+1,2	<100	niobium/mass spec	0	KUTSCHERA 84

<5.E–22		levitated steel	0	MARINELLI	84
<9.E–20	$\pm <13$	water/oil drop	0	JOYCE	83
<2.E–21	$> \pm 1/2 $	levitated steel	0	LIEBOWITZ	83
<1.E–19	$\pm 1,2$	photo ion spec	0	VANDESTEEG	83
<2.E–20		mercury/oil drop	0	³ HODGES	81
1.E–20	+1	levitated niobium	4	⁴ LARUE	81
1.E–20	–1	levitated niobium	4	⁴ LARUE	81
<1.E–21		levitated steel	0	MARINELLI	80B
<6.E–16		helium/mass spec	0	BOYD	79
1.E–20	+1	levitated niobium	2	⁴ LARUE	79
<4.E–28		earth+/ion beam	0	OGOROD...	79
<5.E–15	+1	tungs./mass spec	0	BOYD	78
<5.E–16	+3	<1.7 hydrogen/mass spec	0	BOYD	78B
<1.E–21	$\pm 2,4$	water/ion beam	0	LUND	78
<6.E–15	$>1/2$	levitated tungsten	0	PUTT	78
<1.E–22		metals/mass spec	0	SCHIFFER	78
<5.E–15		levitated tungsten ox	0	BLAND	77
<3.E–21		levitated iron	0	GALLINARO	77
2.E–21	–1	levitated niobium	1	⁴ LARUE	77
4.E–21	+1	levitated niobium	2	⁴ LARUE	77
<1.E–13	+3	<7.7 hydrogen/mass spec	0	MULLER	77
<5.E–27		water+/ion beam	0	OGOROD...	77
<1.E–21		lunar+/ion spec	0	STEVENS	76
<1.E–15	+1	<60 oxygen+/ion spec	0	ELBERT	70
<5.E–19		levitated graphite	0	MORPURGO	70
<5.E–23		water+/atom beam	0	COOK	69
<1.E–17	$\pm 1,2$	levitated graphite	0	BRAGINSK	68
<1.E–17		water+/uv spec	0	RANK	68
<3.E–19	± 1	levitated iron	0	STOVER	67
<1.E–10		sun/uv spec	0	⁵ BENNETT	66
<1.E–17	+1,2	meteorites+/ion beam	0	CHUPKA	66
<1.E–16	± 1	levitated graphite	0	GALLINARO	66
<1.E–22		argon/electrometer	0	HILLAS	59
	–2	levitated oil	0	MILLIKAN	10

¹ 95% CL limit for fractional charge particles with $0.18e \leq |Q_{\text{residual}}| \leq 0.82e$ in total of 70.1 mg of silicone oil.

² 95% CL limit for particles with fractional charge $|Q_{\text{residual}}| > 0.16e$ in total of 17.4 mg of silicone oil.

³ Also set limits for $Q = \pm e/6$.

⁴ Note that in PHILLIPS 88 these authors report a subtle magnetic effect which could account for the apparent fractional charges.

⁵ Limit inferred by JONES 77B.

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