光子
～その質量と電荷～

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光子

- 電磁相互作用を媒介するゲージ粒子
- スピン１　(ボーズ粒子)
  固有値±1をとる　右円偏光、右円偏光に対応
  固有値０は観測できない＝縦波はない
- 質量０
  光は光速で伝わる
  電磁力は無限遠まで伝わる
- 電荷０
  電磁場で曲げられない
- 寿命は無限
  理論的に

http://www.particlezoo.net/individual_pages/shop_photon.html

Review of Particle Physics

- 光子の質量と電荷に上限値
- どんな実験から？　が今回の内容

SUMMARY TABLES OF PARTICLE PROPERTIES

Extracted from the Particle Listings of the
Review of Particle Physics
J. Beringer *et al.*(PDG), PR **D86**, 010001 (2012)
Available at `http://pdg.lbl.gov`

Particle Data Group

J. Beringer, J.-F. Arguin, R.M. Barnett, K. Copic, O. Dahl, D.E. Groom, C.-J. Lin, J. Lys, H. Murayama, C.G. Wohl, W.-M. Yao, P.A. Zyla, C. Amsler, M. Antonelli, D.M. Asner, H. Baer, H.R. Band, T. Basaglia, C.W. Bauer, J.J. Beatty, V.I. Belousov, E. Bergren, G. Bernardi, W. Bertl, S. Bethke, H. Bichsel, O. Biebel, E. Blucher, S. Blusk, G. Brooijmans, O. Buchmueller, R.N. Cahn, M. Carena, A. Ceccucci, D. Chakraborty, M.-C. Chen, R.S. Chivukula, G. Cowan, G. D'Ambrosio, T. Damour, D. de Florian, A. de Gouvêa, T. DeGrand, P. DeJong, G. Dissertori, B. Dobrescu, M. Doser, M. Drees, D.A. Edwards, S. Eidelman, J. Erler, V.V. Ezhela, W. Fetscher, B.D. Fields, B. Foster, T.K. Gaisser, L. Garren, H.-J. Gerber, G. Gerbier, T. Gherghetta, S. Golwala, M. Goodman, C. Grab, A.V. Gritsan, J.-F. Grivaz, M. Grünewald, A. Gurtu, T. Gutsche, H.E. Haber, K. Hagiwara, C. Hagmann, C. Hanhart, S. Hashimoto, K.G. Hayes, M. Heffner, B. Heltsley, J.J. Hernández-Rey, K. Hikasa, A. Höcker, J. Holder, A. Holtkamp, J. Huston, J.D. Jackson, K.F. Johnson, T. Junk, D. Karlen, D. Kirkby, S.R. Klein, E. Klempt, R.V. Kowalewski, F. Krauss, M. Kreps, B. Krusche, Yu.V. Kuyanov, Y. Kwon, O. Lahav, J. Laiho, P. Langacker, A. Liddle, Z. Ligeti, T.M. Liss, L. Littenberg, K.S. Lugovsky, S.B. Lugovsky, T. Mannel, A.V. Manohar, W.J. Marciano, A.D. Martin, A. Masoni, J. Matthews, D. Milstead, R. Miquel, K. Mönig, F. Moortgat, K. Nakamura, M. Narain, P. Nason, S. Navas, M. Neubert, P. Nevski, Y. Nir, K.A. Olive, L. Pape, J. Parsons, C. Patrignani, J.A. Peacock, S.T. Petcov, A. Piepke, A. Pomarol, G. Punzi, A. Quadt, S. Raby, G. Raffelt, B.N. Ratcliff, P. Richardson, S. Roesler, S. Rolli, A. Romaniouk, L.J. Rosenberg, J.L. Rosner, C.T. Sachrajda, Y. Sakai, G.P. Salam, S. Sarkar, F. Sauli, O. Schneider, K. Scholberg, D. Scott, W.G. Seligman, M.H. Shaevitz, S.R. Sharpe, M. Silari, T. Sjöstrand, P. Skands, J.G. Smith, G.F. Smoot, S. Spanier, H. Spieler, A. Stahl, T. Stanev, S.L. Stone, T. Sumiyoshi, M.J. Syphers, F. Takahashi, M. Tanabashi, J. Terning, M. Titov, N.P. Tkachenko, N.A. Törnqvist, D. Tovey, G. Valencia, K. van Bibber, G. Venanzoni, M.G. Vincter, P. Vogel, A. Vogt, W. Walkowiak, C.W. Walter, D.R. Ward, T. Watari, G. Weiglein, E.J. Weinberg, L.R. Wiencke, L. Wolfenstein, J. Womersley, C.L. Woody, R.L. Workman, A. Yamamoto, G.P. Zeller, O.V. Zenin, J. Zhang, R.-Y. Zhu

Technical Associates:

G. Harper, V.S. Lugovsky, P. Schaffner

(Approximate closing date for data: January 15, 2012)

GAUGE AND HIGGS BOSONS

γ

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

Mass $m < 1 \times 10^{-18}$ eV
Charge $q < 1 \times 10^{-35}$ e
Mean life $\tau =$ Stable

~ 1.8×10^{-51} g

光子の質量

Coulomb力の逆二乗則

- 光子に質量があると、Coulomb力が逆二乗則からずれる　1/r^{2+q}
- この q への上限値から、質量への上限値を出す

Maxwell eq. → Proca eq.

$$\left[\nabla^2 - \frac{1}{c^2}\frac{\partial^2}{\partial t^2} - \left(\frac{m_\gamma c}{\hbar}\right)^2\right] A_\mu = -\frac{4\pi}{c} J_\mu$$

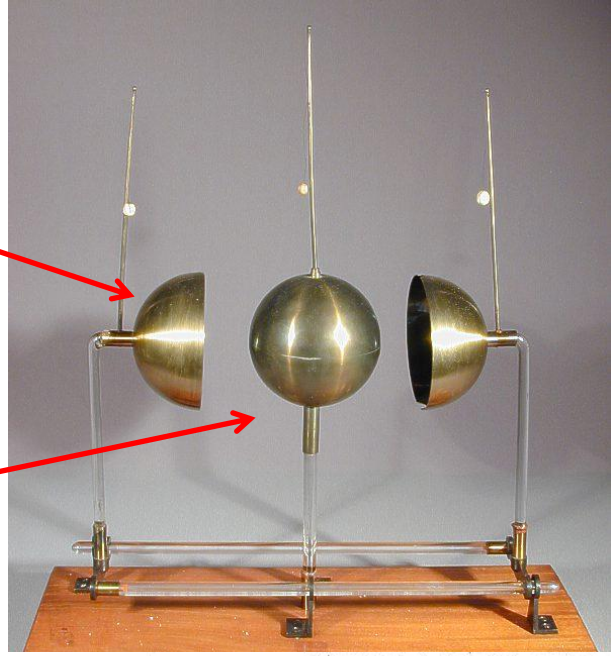
A. Proca: J. Phys. (Paris) **8** (1937) 23.

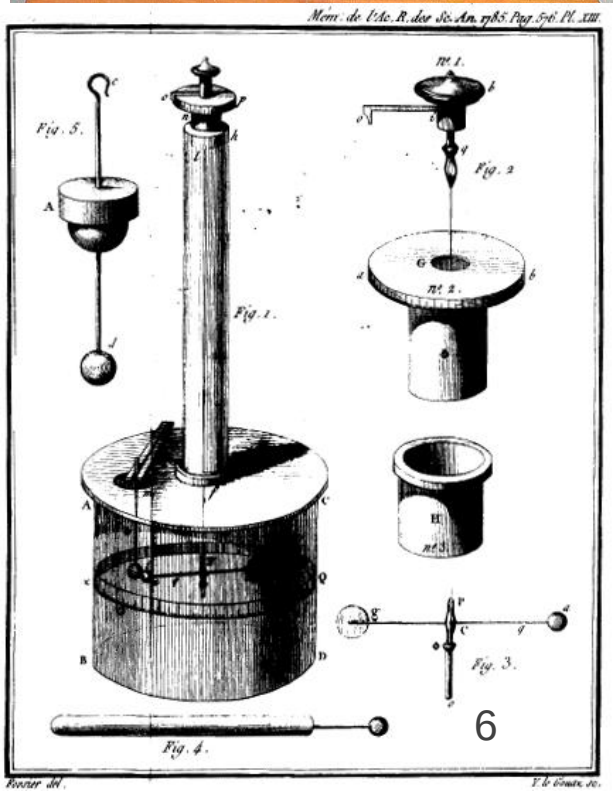
光子のコンプトン波長 μ_γ の逆数

- 光子に質量があっても完全に無矛盾らしい (量子電磁気学でも)

歴史的な実験

- Cavendish (1773)
  q < 2×10^{-2}
  同心導体球殻
- Coulomb (1785)
  q < 4×10^{-2}
  ねじり天秤
- Maxwell (1873)
  q < 4.9×10^{-5}
  同心導体球殻
  当時の電圧計の
  精度で制限





http://www.uibk.ac.at/exphys/museum/html/details/electr/cavendish.html.en
http://en.wikipedia.org/wiki/File:Bcoulomb.png

Plimpton and Lawton (1936)

http://prola.aps.org/abstract/PR/v50/i11/p1066_1

DECEMBER 1, 1936 PHYSICAL REVIEW VOLUME 50

A Very Accurate Test of Coulomb's Law of Force Between Charges

S. J. PLIMPTON AND W. E. LAWTON, *Worcester Polytechnic Institute, Worcester, Massachusetts*

(Received September 30, 1936)

The exponent 2 in Coulomb's inverse square law of force between charges in empty space has been found experimentally to be correct to within 1 part in 10^9. The well-known electrostatic experiment of Cavendish and Maxwell with concentric metal globes was replaced by a quasi-static method in which the difficulties due to spontaneous ionization and contact potentials were avoided. A "resonance electrometer" (undamped galvanometer with amplifier) was placed within the globes, the input resistor of the amplifier forming a permanent link connecting them, so as to measure any variable potential difference between them. It was shown theoretically that the presence of the resonance electrometer would have no effect on the result and that it could replace electrically a part of the inner globe. The galvanometer was observed through a "conducting window" at the top, made so by covering it with salt water. No effect was observed when a harmonically alternating high potential V (>3000 volts), from a specially designed "condenser generator" operating at the low resonance frequency of the galvanometer, was applied to the outer globe. The sensitivity was such that a voltage $v=10^{-6}$ volt was easily observable above the small fluctuations due to Brownian motion.

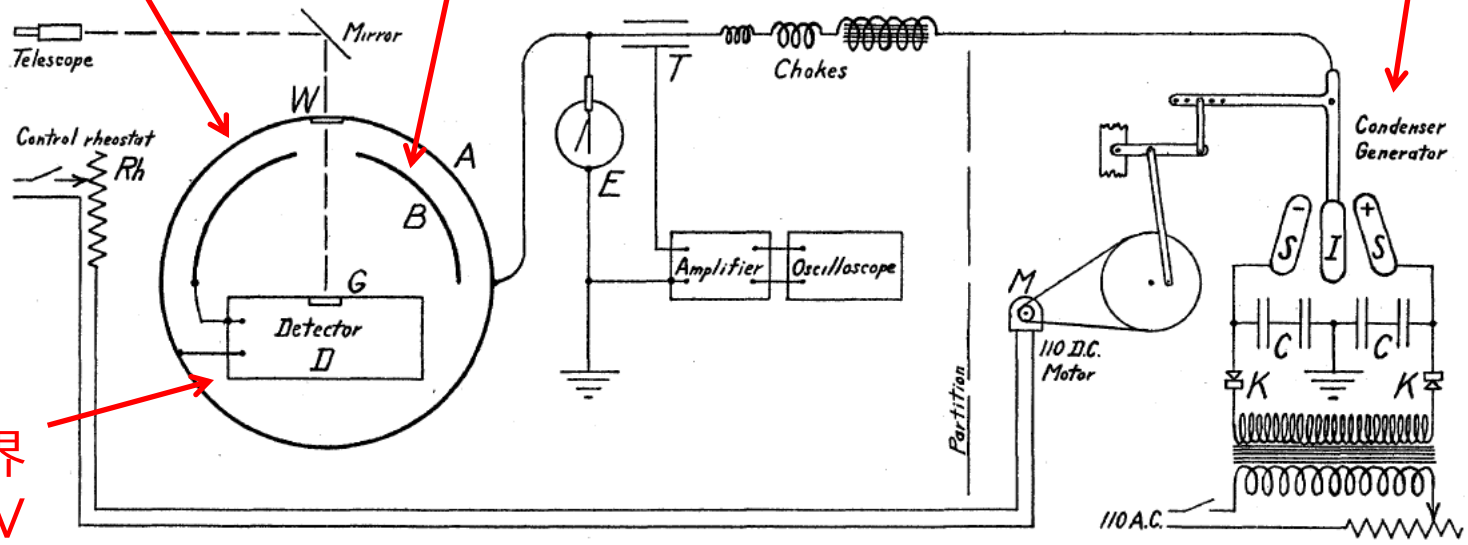
If the exponent in the law of force were not exactly 2 but rather $2\pm q$ then $q<v/VF(a, b)$ where $F(a, b)=0.169$, a and b being the radii of the globes. This gives $q<2\times10^{-9}$ in space remote from matter. The formula for $F(a, b)$ was derived by Maxwell's theory in which the effect of gravity is assumed negligible. Reasons are given for believing that this assumption does not invalidate the result.

Plimpton and Lawton (1936)

- 導体のspontaneous ionizationと接触電位が問題
  外殻に加える電圧を変調
  Detector(検流計)を中に入れる
- q < 2×10^{-9}
  → m_γ < 3.4×10^{-44} g

直径1.5 m, 鉄　直径1.2 m, 鉄

電圧を変調させるための装置
3000 V, 2 Hz



検出限界
~1 uV

FIG. 1. Apparatus for testing the inverse square law of force between charges.

Williams+ (1971)

http://prl.aps.org/abstract/PRL/v26/i12/p721_1

York, 1966).
[2]H. A. Bethe, Z. Phys. 71, 205 (1931); L. Hulthén, Arkiv. Mat. Astron. Fys. 26A, No. 11 (1938).
[3]J. des Cloizeaux and J. J. Pearson, Phys. Rev. 128, 2131 (1962).
[4]M. E. Fisher, Amer. J. Phys. 32, 343 (1964).
[5]The most thoroughly studied system of this type is $CsMnCl_3 \cdot 2H_2O$. See J. Skalyo, Jr., G. Shirane, S. A. Friedberg, and H. Kobayashi, Phys. Rev. B 2, 1310, 4632 (1970).
[6]R. Dingle, M. E. Lines, and S. L. Holt, Phys. Rev. 187, 643 (1969).
[7]B. Morosin and E. J. Graeber, Acta Crystallogr. 23, 766 (1967).
[8]For a review see W. Marshall and R. D. Lowde, Rep. Progr. Phys. 31, 705 (1968).
[9]For $\vec{k}_f$ perpendicular to the chains, Eq. (1) is nearly exact. See R. J. Birgeneau, J. Skalyo, Jr., and G. Shirane, to be published.
[10]R. J. Birgeneau, H. J. Guggenheim, and G. Shirane, Phys. Rev. Lett. 22, 720 (1969).
[11]In this paper, for convenience, all momenta are referred to the room-temperature hexagonal axes. There is a small monoclinic distortion at 128°K, but this is not of importance here.
[12]M. T. Hutchings, G. Shirane, R. J. Birgeneau, R. Dingle, and S. L. Holt, to be published.
[13]F. B. McLean and M. Blume, to be published.

New Experimental Test of Coulomb's Law: A Laboratory Upper Limit on the Photon Rest Mass

E. R. Williams,* J. E. Faller, and H. A. Hill
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(Received 22 January 1971)

A high-frequency test of Coulomb's law is described. The sensitivity of the experiment is given in terms of a finite photon rest mass using the Proca equations. The null result of our measurement expressed in the form of the photon rest mass squared is $\mu^2 = (1.04 \pm 1.2) \times 10^{-19}$ cm^{-2}. Expressed as a deviation from Coulomb's law of the form $1/r^{2+q}$, our experiment gives $q = (2.7 \pm 3.1) \times 10^{-16}$. This result extends the validity of Coulomb's law by two orders of magnitude.

Williams+ (1971)

- 5殻の同心正二十面体
- 高周波で電圧を変調(4 MHz)
- 検出限界　~10^{-12} V
- q = (2.7±3.1)×10^{-16}
  → m_γ < 1.6×10^{-47} g

10 kV, 4 MHz

直径1.5 m

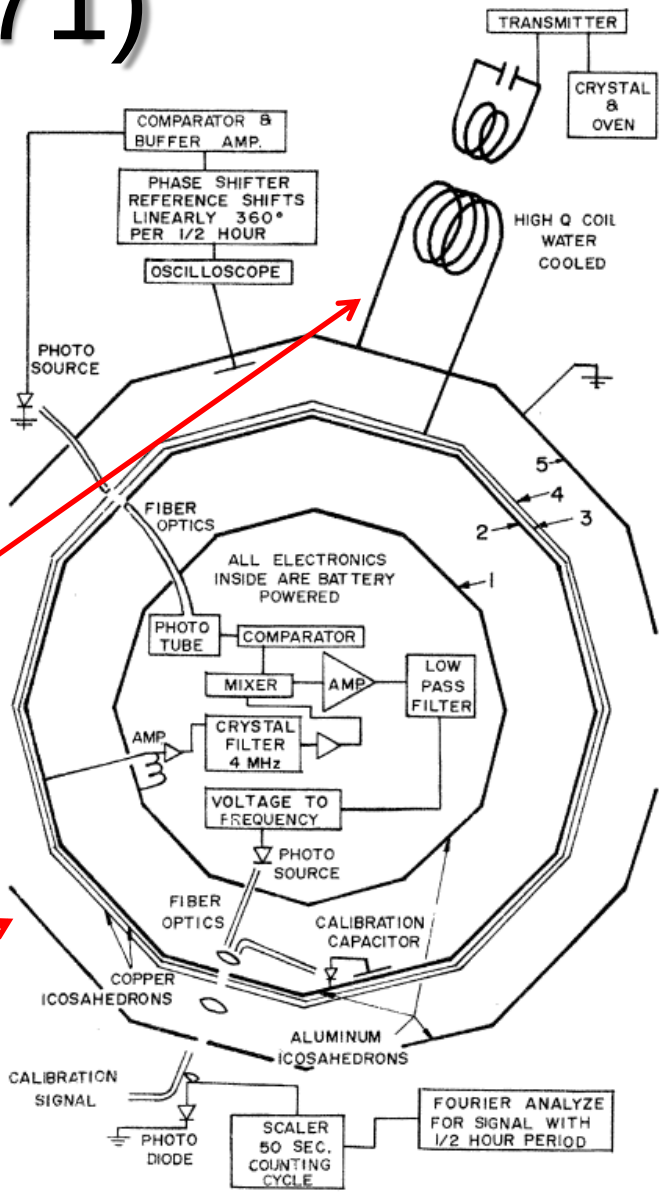

FIG. 1. Schematic drawing of the apparatus. A 4-MHz voltage is applied between shells 4 and 5. A signal of less than 10^{-12} V could have been detected between shells 1 and 2.

Goldhaber and Nieto (1968)

http://prl.aps.org/abstract/PRL/v21/i8/p567_1

VOLUME 21, NUMBER 8 PHYSICAL REVIEW LETTERS 19 AUGUST 1968

NEW GEOMAGNETIC LIMIT ON THE MASS OF THE PHOTON

Alfred S. Goldhaber and Michael Martin Nieto*
Institute for Theoretical Physics, State University of New York at Stony Brook, Stony Brook, New York 11790
(Received 25 June 1968)

On the basis of recent precise data on the earth's magnetic field, a new upper bound on the mass of the photon is obtained using a method that was originally proposed by Schrödinger. The limit is 1.15×10^{-10} cm$^{-1}\equiv2.3\times10^{-15}$ eV$\equiv4.0\times10^{-48}$ g, which is four orders of magnitude better than the best laboratory measurement, that of Plimpton and Lawton.

もともとはE. Schrödingerが初めてやったらしい。
Proc. Roy. Irish Acad., A, 49, 43 (1943)　だけどオンラインでは見つからず。

Goldhaber and Nieto (1968)

- 地球磁場でAmpereの法則を検証
- 地球磁場を双極子だとし、そこに外部磁場が加わった時、地上での磁場はどうなるか
  地上、人工衛星での観測を元に
- $m_\gamma < 4.0\times10^{-48}$ g

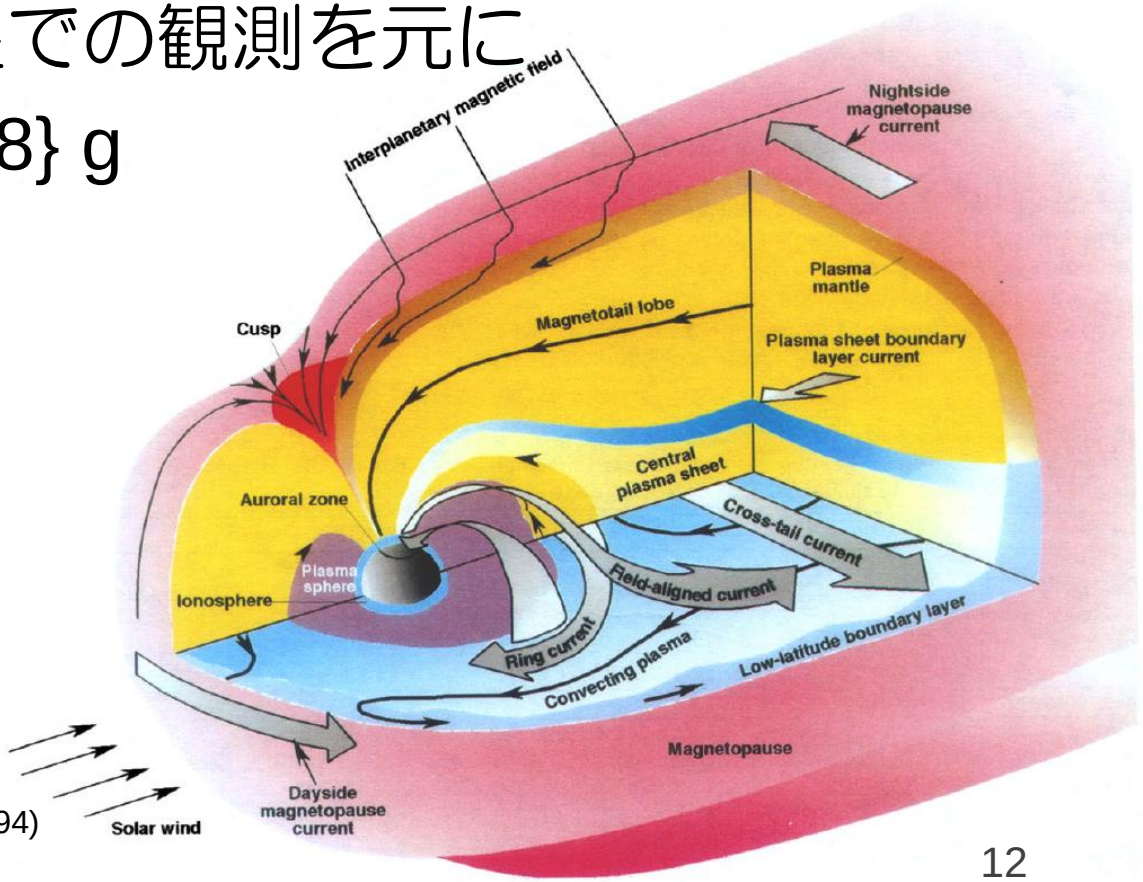

FIG. 1. Dominant space plasma current systems shown in a "cut-away" view of the Earth's magnetosphere.

E. Fischbach: Phys. Rev. Lett. 73, 514–517 (1994)
http://prl.aps.org/abstract/PRL/v73/i4/p514_1

Davis+ (1975)

- 木星磁場から
- m_γ < 8×10^{-49} g

http://prl.aps.org/abstract/PRL/v35/i21/p1402_1

VOLUME 35, NUMBER 21 PHYSICAL REVIEW LETTERS 24 NOVEMBER 1975

Limit on the Photon Mass Deduced from Pioneer-10 Observations of Jupiter's Magnetic Field*

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and

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and

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(Received 9 July 1975)

We report an analysis of the Pioneer-10 data on Jupiter's magnetic field, in which the mass μ of the photon was treated as a free parameter. We set a limit of $\mu \leq 2 \times 10^{-11}$ cm^{-1} $\equiv 6 \times 10^{-16}$ eV $\equiv 8 \times 10^{-49}$ g. This is the smallest limit so far obtained from direct measurements. We compare our result with other published limits.

Lakes (1998)

http://prl.aps.org/abstract/PRL/v80/i9/p1826_1

VOLUME 80, NUMBER 9 PHYSICAL REVIEW LETTERS 2 MARCH 1998

Experimental Limits on the Photon Mass and Cosmic Magnetic Vector Potential

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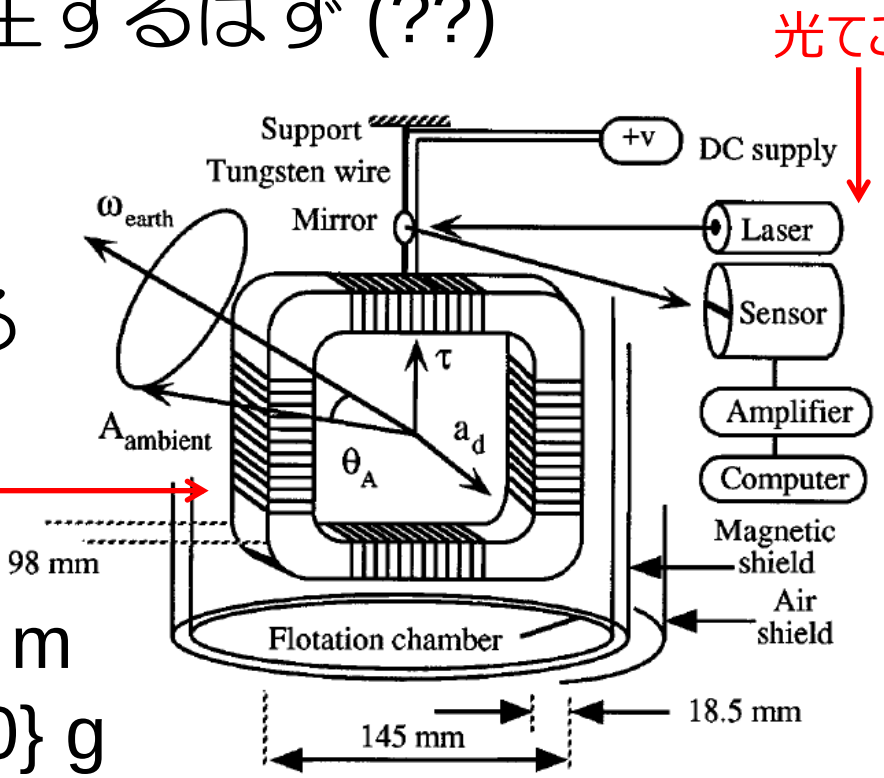
(Received 2 June 1997; revised manuscript received 11 December 1997)

A novel experimental approach based on a toroid Cavendish balance is used to evaluate the product of photon mass squared and the ambient cosmic magnetic vector potential A. The method is based on the energy density of the vector potential in the presence of photon mass, not on measurement of the magnetic field. The experiment discloses $A\mu_\gamma^2 < 2 \times 10^{-9}$ T m/m^2, with μ_γ^{-1} as the characteristic length associated with photon mass. Consequently, if the ambient magnetic vector potential is $A \approx 10^{12}$ T m due to cluster level fields, $\mu_\gamma^{-1} > 2 \times 10^{10}$ m. If we conservatively use galactic fields prior to a reversal, then $\mu_\gamma^{-1} > 1 \times 10^9$ m, a figure still superior to that derived from the Jovian magnetic field. [S0031-9007(98)05451-9]

PACS numbers: 12.20.Fv, 14.70.Bh, 41.20.Jb, 98.80.Cq

Lakes (1998)

- トロイドが作る双極子磁場とambient cosmic vector potentialの相互作用を測定。もし光子に質量があるならトルクが発生するはず (??)
- 18ヶ月測定
- A (μ_γ)^2の積を測定
  Aの大きさに仮定が入る



- (μ_γ)^{-1} > 2×10^{10} m
  → m_γ < 1.8×10^{-50} g

FIG. 1. A toroid carries an electric current giving rise to a dipole field $\mathbf{a}_d$ in magnetic vector potential. If $\mu_\gamma > 0$, this interacts with the ambient vector potential $\mathbf{A}_{ambient}$ to produce a torque τ on the toroid, which varies with time according to the rotation ω of Earth.

Luo+ (2003)

http://prl.aps.org/abstract/PRL/v90/i8/e081801

VOLUME 90, NUMBER 8 PHYSICAL REVIEW LETTERS week ending 28 FEBRUARY 2003

New Experimental Limit on the Photon Rest Mass with a Rotating Torsion Balance

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(Received 24 August 2002; published 26 February 2003)

A rotating torsion balance method is used to detect the product of the photon mass squared and the ambient cosmic vector potential $\boldsymbol{A}_e$. The signal is modulated by rotating the torsion balance to ensure the effectiveness of detection for all possible orientations of the vector potential. The influences of sidereal disturbances of environment are also removed by virtue of this modulation method. The experimental result shows $\mu_\gamma^2 A_e < 1.1 \times 10^{-11}\ \mathrm{T\,m/m^2}$, with μ_γ^{-1} as the characteristic length associated with photon mass. If the ambient cosmic vector potential $\boldsymbol{A}_e$ is $10^{12}\ \mathrm{T\,m}$ due to cluster level fields, we obtain a new upper limit on photon mass of 1.2×10^{-51} g.

DOI: 10.1103/PhysRevLett.90.081801 PACS numbers: 12.20.Fv, 14.70.Bh, 98.80.Cq

Luo+ (2003)

- Lakes(1998)と同様だが、ねじれ振り子を回転
  共振6 mHz、1 回転/hour
- m_γ < 1.2×10^{-51} g

17.5 mrad/V

回転周期の半分

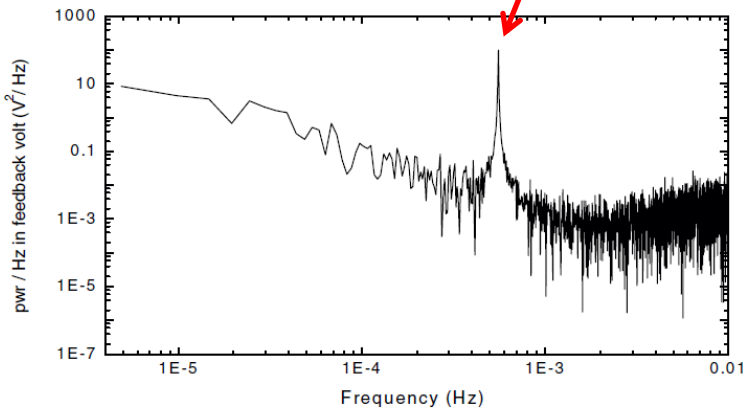


FIG. 3. The power density spectrum of the feedback voltage over 72 hours. The most obvious peak at half an hour is due to the gravitational gradient effect of the experiment site, which is the double frequency of the modulation. The rise of the low energy tail above 2×10^{-3} Hz is due to the damped free resonance of the pendulum.

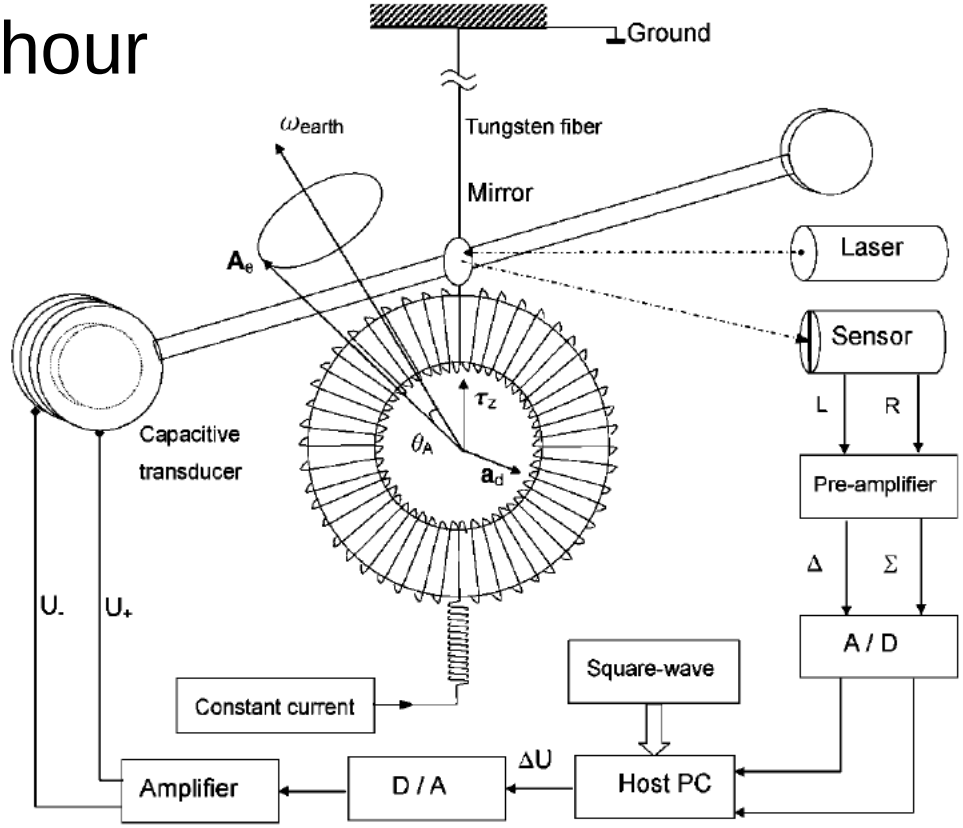


FIG. 1. The experimental setup of the rotating torsion balance. The magnetic dipole vector potential moment $\boldsymbol{a}_d$ arising from the toroidal coil interacts with the cosmic vector potential $\boldsymbol{A}_e$ to produce a torque on the torsion balance. This torque associated with the effect of photon mass varies with time according to the rotation of the torsion balance.

その他の実験1

- Aharonov-Bohm効果のずれを見る(提案)

  D. D. Boulware and S. Deser
  PRL **21** (1989) 2319.

  G. Spavieri and M. Rodriguez
  PRA **75** (2007) 052113.
  $m_\gamma < 10^{-51}$ g はいける

- イオン干渉計で逆二乗を検証(提案)

  B. Neyenhuis *et al.*: PRL **99** (2007) 200401.
  $m_\gamma < 9\times10^{-50}$ g はいける

- 冥王星での太陽風観測

  D. D. Ryutov: Plasma Phys. Control. Fusion **49** (2007) B429.
  $m_\gamma < 1.5\times10^{-51}$ g

その他の実験2

- 光速に波長依存性が出る(分散)

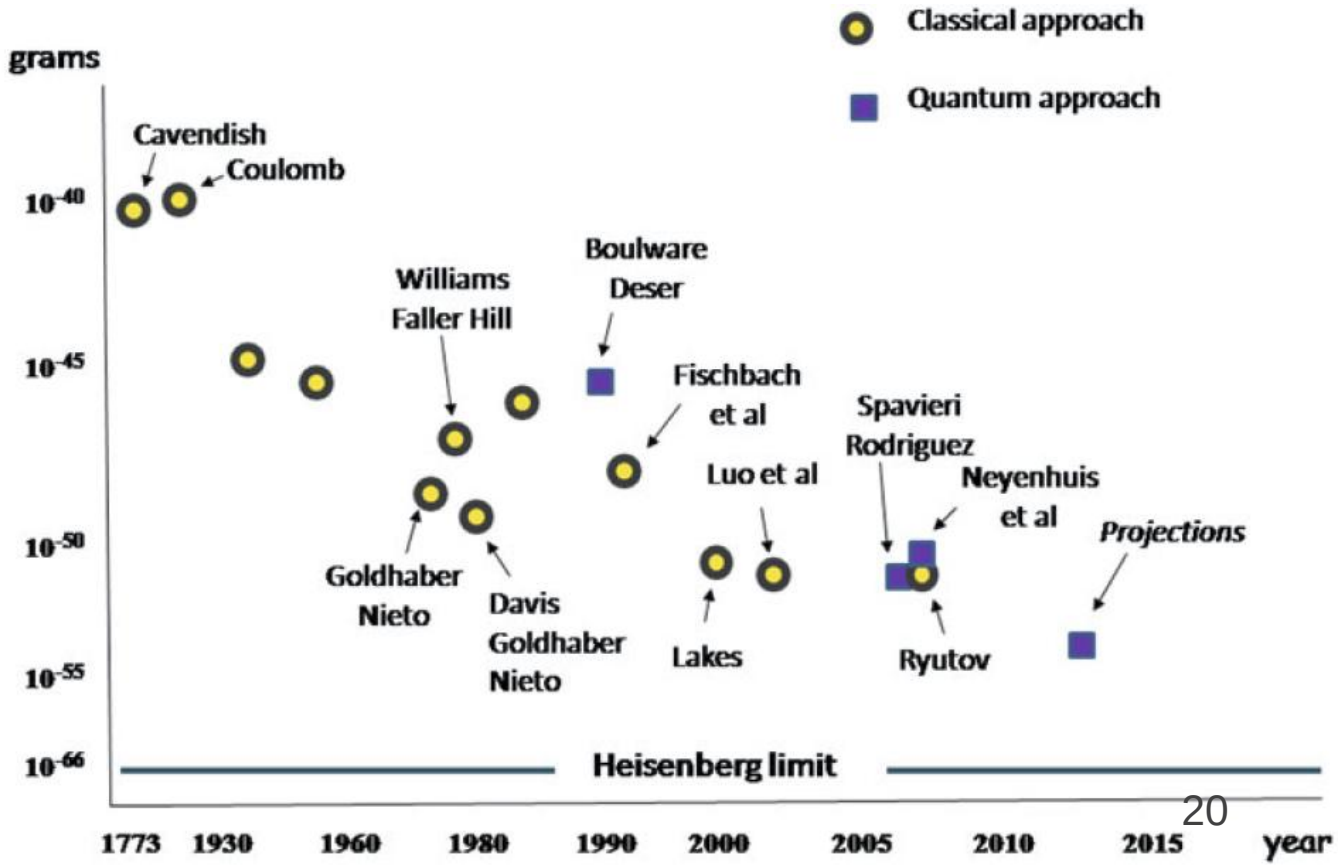
  L. de Broglie (1940)
  連星からの光
  m_γ < 7.8×10^{-39} g

  G. Feinberg: Science **166** (1969) 879.
  Crab pulsar NP0532
  m_γ < 10^{-44} g

- 光の縦波探索
  光子系に蓄えられるエネルギーが50%増えてしまうが、Planckの法則は精度よく確かめられている。縦波が熱平衡に達するのに時間かかるから観測が難しいだけという説も。

参考文献

- A survey of existing and proposed classical and quantum approaches to the photon mass
  G. Spavieri *et al.*: Eur. Phys. J D **61** (2011) 531.
- Terrestrial and Extraterrestrial Limits on The Photon Mass
  A. S. Goldhaber and M. M. Nieto: Rev. Mod. Phys. **43** (1971) 277.



光子の電荷

これまでの実験

- 下記の表でほぼ全て

Authors	Year	q/e	Interaction source	Photon source
Grodzins et al.[15]	1961	10^{-15}	Electric field	Decay of Fe^{57} (laboratory test)
Stover et al.[16]	1967	10^{-16}	Electric field	Laser (laboratory test)
Present work	2012	10^{-14}	Electric field	Laser (laboratory test)
Cocconi[11]	1992	10^{-28}	Magnetic field	Extragalactic radiation
Cocconi & Raffelt[9,10]	1994	10^{-28}	Magnetic field	Radio pulsars
Sivaram[13]	1994	10^{-27}	Charge asymmetry	CMB
Semertzidis et al.[17]	2003	10^{-16}	Magnetic field	Laser (laboratory test)
Kobychev and Popov[12]	2005	10^{-31} & 10^{-33}	Magnetic field	Extragalactic radiation
Caprini and Ferreira[14]	2005	10^{-38}	Charge asymmetry	CMB
Altschul[8]	2007	10^{-32} & 10^{-46}	Magnetic field	Extragalactic radiation
Sivaram and Arun[19]	2010	10^{-30}	Magnetic field	Hawking radiation from a black hole

TABLE I. Status of upper limits on the photon charge: There have been three laboratory tests to constrain the photon charge; two of them employ electric fields, one by Grodzins et al.[15] and the other by Stover et al.[16], and the third one involves magnetic deflection[17]. Even the best limit among the three laboratory tests is at least ten orders of magnitude weaker than the limit obtained from charge asymmetry in the CMB data[13], which is the least stringent bound among those based on astrophysical observations.

http://arxiv.org/abs/1209.2052v1

Caprini & Ferreira (2005)

http://prl.aps.org/abstract/PRL/v98/i26/e261801

- CMBの異方性が光子が電荷を持っているためだとして説明すると
- 光子の電荷は片方のみだと仮定
- e_γ/e < 10^{-35}
- モデル依存性が大きい

Constraints on the electrical charge asymmetry of the universe

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doi:10.1088/1475-7516/2005/02/006

Abstract. We use the isotropy of the cosmic microwave background to place stringent constraints on a possible electrical charge asymmetry of the universe. We find the excess charge per baryon to be $q_{e-p} < 10^{-26}e$ in the case of a uniform distribution of charge, where e is the charge of the electron. If the charge asymmetry is inhomogeneous, the constraints will depend on the spectral index, n, of the induced magnetic field and range from $q_{e-p} < 5 \times 10^{-20}e$ $(n = -2)$ to $q_{e-p} < 2 \times 10^{-26}e$ $(n \geq 2)$. If one could further assume that the charge asymmetries of individual particle species are not anti-correlated so as to cancel, this would imply, for photons, $q_\gamma < 10^{-35}e$; for neutrinos, $q_\nu < 4 \times 10^{-35}e$; and for heavy (light) dark matter particles $q_{dm} < 4 \times 10^{-24}e$ ($q_{dm} < 4 \times 10^{-30}e$).

Keywords: CMBR theory, physics of the early universe

JCAP02(2005)006

Altschul (2007)

http://prl.aps.org/abstract/PRL/v98/i26/e261801

- 銀河系外からの放射光
  電荷があったらAharonov-Bohm効果で位相がずれる
- 光子が両方の電荷なら e_γ/e < 10^{-32}
  片方の電荷なら e_γ/e < 10^{-46}

PRL 98, 261801 (2007) PHYSICAL REVIEW LETTERS week ending 29 JUNE 2007

Bound on the Photon Charge from the Phase Coherence of Extragalactic Radiation

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(Received 28 March 2007; published 27 June 2007)

If the photon possessed a nonzero charge, then electromagnetic waves traveling along different paths would acquire Aharonov-Bohm phase differences. The fact that such an effect has not hindered interferometric astronomy places a bound on the photon charge estimated to be at the $10^{-32}e$ level if all photons have the same charge and $10^{-46}e$ if different photons can carry different charges.

DOI: 10.1103/PhysRevLett.98.261801 PACS numbers: 14.70.Bh, 03.65.Vf, 13.40.Em, 95.75.Kk

Semertzidis+ (2003)

http://prd.aps.org/abstract/PRD/v67/i1/e017701

PHYSICAL REVIEW D **67**, 017701 (2003)

New laboratory technique for measuring the photon charge

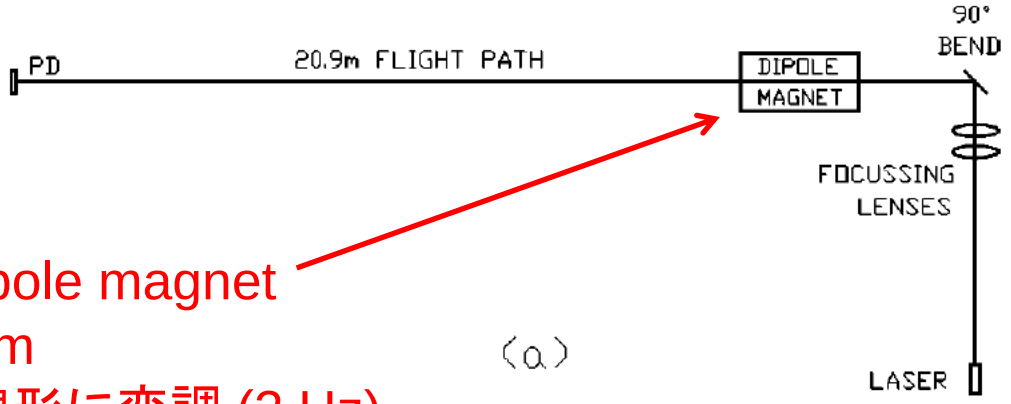
Y. K. Semertzidis, G. T. Danby, and D. M. Lazarus*
Brookhaven National Laboratory, Upton, New York 11973
(Received 9 August 2002; published 9 January 2003)

A measurement of the deflection of a laser beam in a modulated magnetic field with a prototype apparatus has produced an upper limit on the charge of the photon of $8.5\times10^{-17}e$. It is shown that an improved apparatus could attain a sensitivity of $10^{-21}e$.

DOI: 10.1103/PhysRevD.67.017701 PACS number(s): 14.70.Bh

Semertzidis+ (2003)

- レーザー(He-Ne)と磁場
- e_γ/e < 8.5×10^{-17}



AGS booster dipole magnet
有効磁石長 2.4 m
0-0.73 Teslaで線形に変調 (2 Hz)

- さらに感度向上

  磁場強度を上げる
  変調周波数を上げる
  FPを使う
  10^{-21}はいける

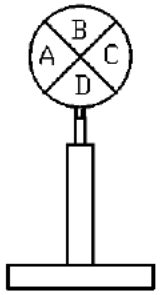


FIG. 1. (a) Apparatus: The light from the laser is focused at the position of the quad photodiode by the lens doublet immediately before the 45° mirror which positions the beam focus by means of horizontal and vertical micrometer angular adjustment. (b) Photodiode configuration.

Haskins+ (2012)

http://arxiv.org/abs/1209.2052v1

Laboratory limit on the charge of photons by electric field deflection

A. Hankins, C. Rackson, and W. J. Kim*
901 12th Ave Department of Physics, Seattle University, Seattle, WA 98122, USA
(Dated: September 11, 2012)

The deflection of a laser beam traveling through a modulated electric field is measured using phase-sensitive detection to place an upper bound on photon charge. An upper limit of $10^{-14}e$ is obtained. The experiment involves a number of experimental techniques that are commonly encountered in modern precision measurements and is suitable for both advanced undergraduate and beginning graduate students in physical science as a laboratory exercise.

Haskins+ (2012)

- レーザー(667 nm)と電場
  - 電場を使って直接的に測定したのは初
  - 学部生レベルのセットアップ
- e_γ/e < 2.3×10^{-14}
- 2 kVにして
  有効極板長50cmに
  すれば2桁更新可能

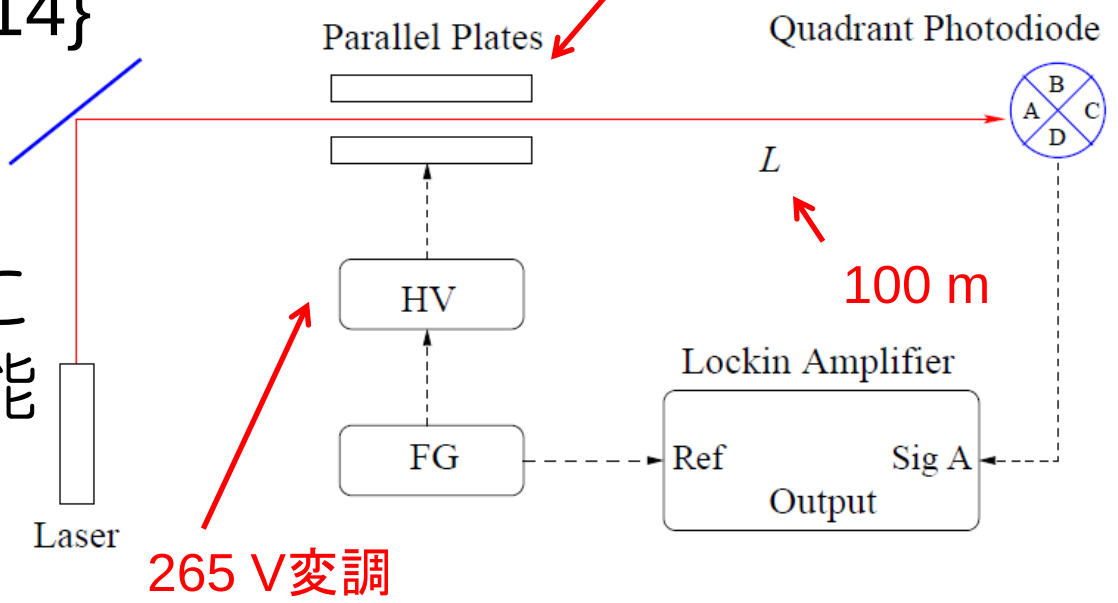
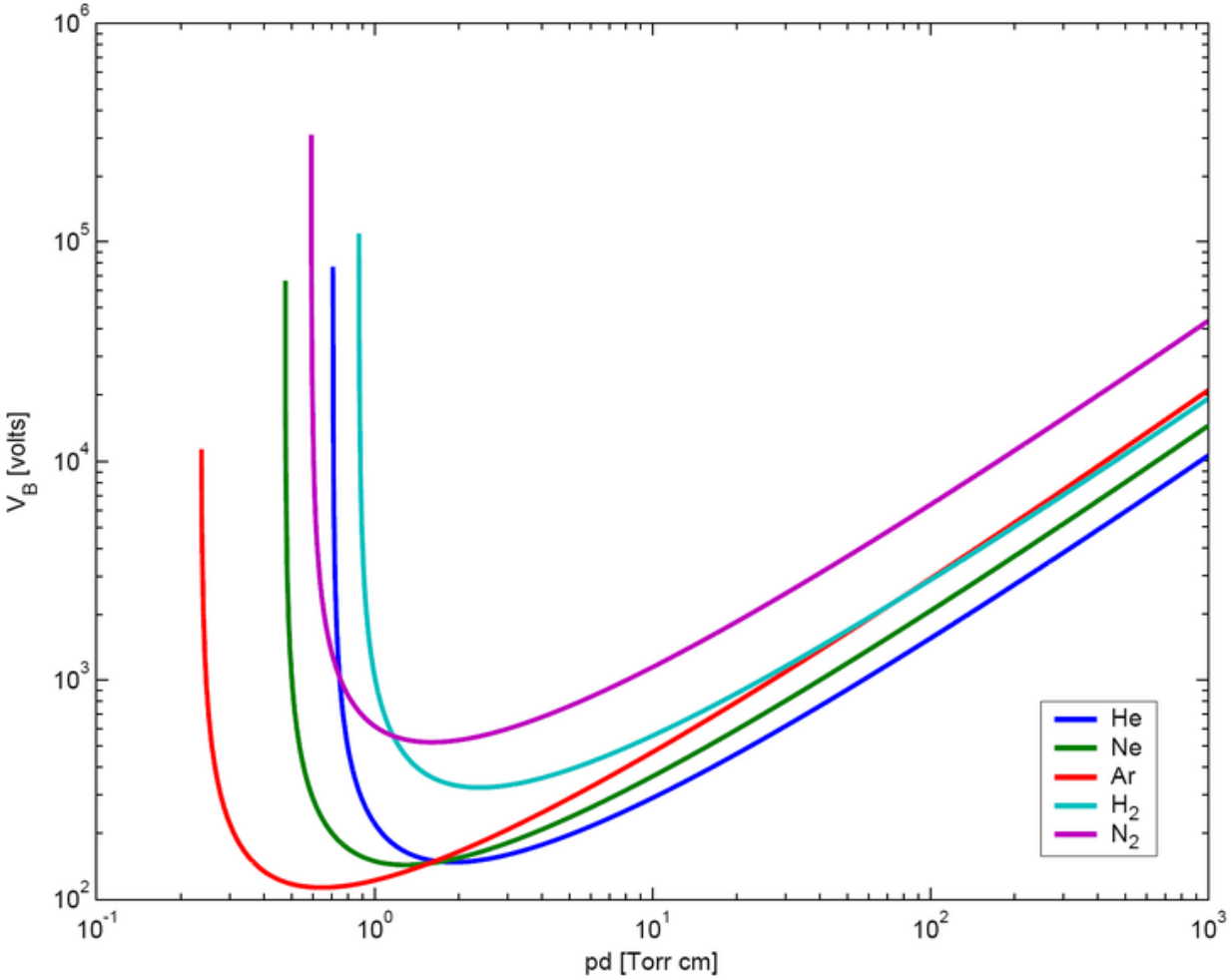


FIG. 1. Experimental setup: The electric field (V/d) across the parallel plates is modulated with the upper plate grounded, and the subsequent light "deflection" is measured from the lock-in output.

パッシェンの法則

- 放電が起こる限界



http://en.wikipedia.org/wiki/File:Paschen_Curves.PNG

光子が電荷を持つのはおかしい

- L. B. Okun: arXiv:hep-ph/0505250v1
  On the charge of the photon
- これまでの実験は光子が電荷を持つとした場合の電磁気学の変更を無視している
- 電荷保存するなら、電荷+と-の2種類必要
- Yang-Mills理論なら、電荷0も含めた3種類必要
- そうすると電子やミューオン等にも種類があることになる
- 標準理論の totality of data に反する

まとめ

- 光子の質量

  理論的に面白そうだが、
  上限値がきつい

- 光子の電荷

  上限値更新できるかもしれないけど、
  理論的に面白くなさそう

- やりたい人はやればいいと思います