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Anomalous magnetic dipole moment

In quantum electrodynamics, the **anomalous magnetic moment** of a particle is a contribution of effects of quantum mechanics, expressed by Feynman diagrams with loops, to the magnetic moment of that particle. (The *magnetic moment*, also called *magnetic dipole moment*, is a measure of the strength of a magnetic source.)

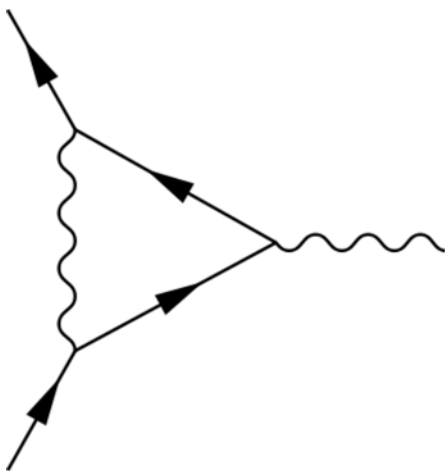
The "Dirac" magnetic moment, corresponding to tree-level Feynman diagrams (which can be thought of as the classical result), can be calculated from the Dirac equation. It is usually expressed in terms of the g-factor; the Dirac equation predicts $g = 2$. For particles such as the electron, this classical result differs from the observed value by a small fraction of a percent. The difference is the anomalous magnetic moment, denoted a and defined as

$$a = \frac{g-2}{2}$$

Contents

Electron
Muon
Tau
Composite particles
See also
Notes
Bibliography
External links

Electron



One-loop correction to the fermion's magnetic dipole moment.

The one-loop contribution to the anomalous magnetic moment—corresponding to the first and largest quantum mechanical correction—of the electron is found by calculating the vertex function shown in the adjacent diagram. The calculation is relatively straightforward[1] and the one-loop result is:

$$a_e = \frac{\alpha}{2\pi} \approx 0.001\ 161\ 4$$

where α is the fine structure constant. This result was first found by Julian Schwinger in 1948[2] and is engraved on his tombstone. As of 2016, the coefficients of the QED formula for the anomalous magnetic moment of the electron are known analytically up to α^3[3] and have been calculated up to order α^5:[4][5][6]

$$a_e = 0.001\ 159\ 652\ 181\ 643(764)$$

The QED prediction agrees with the experimentally measured value to more than 10 significant figures, making the magnetic moment of the electron the most accurately verified prediction in the history of physics. (See precision tests of QED for details.)

The current experimental value and uncertainty is:[7]

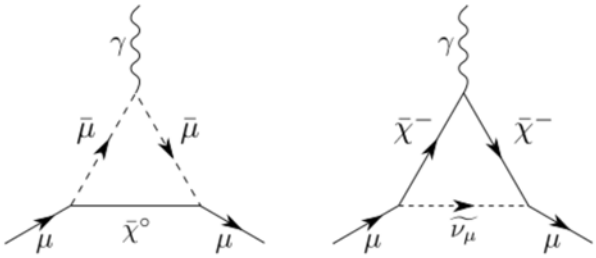
$$a_e = 0.001\ 159\ 652\ 180\ 73(28)$$

According to this value, a_e is known to an accuracy of around 1 part in 1 billion (10^9). This required measuring g to an accuracy of around 1 part in 1 trillion (10^{12}).

Muon

The anomalous magnetic moment of the muon is calculated in a similar way to the electron. The prediction for the value of the muon anomalous magnetic moment includes three parts:[8]

$$\begin{aligned} a_\mu^{\text{SM}} &= a_\mu^{\text{QED}} + a_\mu^{\text{EW}} + a_\mu^{\text{Hadron}} \\ &= 0.001\ 165\ 918\ 04(51) \end{aligned}$$



One-loop MSSM corrections to the muon g−2 involving a neutralino and a smuon, and a chargino and a muon sneutrino respectively.

The first two components represent the photon and lepton loops, and the W boson, Higgs boson and Z boson loops, respectively, and can be calculated precisely from first principles. The third term represents hadron loops, and cannot be calculated accurately from theory alone. It is estimated from experimental measurements of the ratio of hadronic to muonic cross sections (R) in electron–antielectron (e^-e^+) collisions. As of July 2017, the measurement disagrees with the Standard Model by 3.5 standard deviations,[9] suggesting physics beyond the Standard Model may be having an effect (or that the theoretical/experimental errors are not completely under control). This is one of the long-standing discrepancies between the Standard Model and experiment.

The E821 experiment at Brookhaven National Laboratory (BNL) studied the precession of muon and antimuon in a constant external magnetic field as they circulated in a confining storage ring.[10] The E821 Experiment reported the following average value[8]

$$a_\mu = 0.001\ 165\ 920\ 9(6).$$

A new experiment at Fermilab called "Muon g−2" using the E821 magnet will improve the accuracy of this value.[11] Data taking began in 2017 and will continue for three years.[12]

Tau

Standard Model prediction for tau's anomalous magnetic dipole moment is:

$$a_\tau = 0.001\ 177\ 21(5)$$

while best measured bound for a_τ is:

$$-0.007 < a_\tau < 0.005$$[13]

Composite particles

Composite particles often have a huge anomalous magnetic moment. This is true for the proton, which is made up of charged quarks, and the neutron, which has a magnetic moment even though it is electrically neutral.

See also

- Anomalous electric dipole moment
- G-factor
- Proton magnetic moment
- Neutron magnetic moment
- Electron magnetic moment
- Gordon decomposition

Notes

1. Peskin, M. E.; Schroeder, D. V. (1995). "Section 6.3". *An Introduction to Quantum Field Theory*. Addison-Wesley. ISBN 978-0-201-50397-5.
2. Schwinger, J. (1948). "On Quantum-Electrodynamics and the Magnetic Moment of the Electron" (http://web.ihep.su/dbserv/compas/src/schwinger48b/eng.pdf) (PDF). *Physical Review*. **73** (4): 416. Bibcode:1948PhRv...73..416S (https://ui.adsabs.harvard.edu/abs/1948PhRv...73..416S). doi:10.1103/PhysRev.73.416 (https://doi.org/10.1103%2FPhysRev.73.416).
3. Laporta, S.; Remiddi, E. (1996). "The analytical value of the electron (g − 2) at order α^3 in QED". *Physics Letters B*. **379**: 283–291. arXiv:hep-ph/9602417 (https://arxiv.org/abs/hep-ph/9602417). Bibcode:1996PhLB..379..283L (https://ui.adsabs.harvard.edu/abs/1996PhLB..379..283L). doi:10.1016/0370-2693(96)00439-X (https://doi.org/10.1016%2F0370-2693%2896%2900439-X).
4. Aoyama, T.; Hayakawa, M.; Kinoshita, T.; Nio, M. (2012). "Tenth-Order QED Contribution to the Electron g−2 and an Improved Value of the Fine Structure Constant". *Physical Review Letters*. **109** (11): 111807. arXiv:1205.5368 (https://arxiv.org/abs/1205.5368). Bibcode:2012PhRvL.109k1807A (https://ui.adsabs.harvard.edu/abs/2012PhRvL.109k1807A). doi:10.1103/PhysRevLett.109.111807 (https://doi.org/10.1103%2FPhysRevLett.109.111807). PMID 23005618 (https://www.ncbi.nlm.nih.gov/pubmed/23005618).
5. Aoyama, Tatsumi; Hayakawa, Masashi; Kinoshita, Toichiro; Nio, Makiko (1 February 2015). "Tenth-Order Electron Anomalous Magnetic Moment — Contribution of Diagrams without Closed Lepton Loops". *Physical Review D*. **91** (3): 033006. arXiv:1412.8284 (https://arxiv.org/abs/1412.8284). Bibcode:2015PhRvD..91c3006A (https://ui.adsabs.harvard.edu/abs/2015PhRvD..91c3006A). doi:10.1103/PhysRevD.91.033006 (https://doi.org/10.1103%2FPhysRevD.91.033006).
6. Nio, Makiko (3 February 2015). *QED tenth-order contribution to the electron anomalous magnetic moment and a new value of the fine-structure constant* (http://www.bipm.org/cc/CODATA-TGFC/Allowed/2015-02/Nio.pdf) (PDF). Fundamental Constants Meeting 2015 (http://www.bipm.org/cc/AllowedDocuments.jsp?cc=CODATA-TGFC). Eltville, Germany.
7. Hanneke, D.; Fogwell Hoogerheide, S.; Gabrielse, G. (2011). "Cavity Control of a Single-Electron Quantum Cyclotron: Measuring the Electron Magnetic Moment" (http://gabrielse.physics.harvard.edu/gabrielse/papers/2011/ElectronMagneticMomentMeasurements.pdf) (PDF). *Physical Review A*. **83** (5): 052122. arXiv:1009.4831 (https://arxiv.org/abs/1009.4831). Bibcode:2011PhRvA..83e2122H (https://ui.adsabs.harvard.edu/abs/2011PhRvA..83e2122H). doi:10.1103/PhysRevA.83.052122 (https://doi.org/10.1103%2FPhysRevA.83.052122).
8. Patrignani, C.; Agashe, K. (2016). "Review of Particle Physics" (http://inspirehep.net/record/1489868/files/openaccess_cpc_40_10_100001.pdf) (PDF). *Chinese Physics C*. IOP Publishing. **40** (10): 100001. doi:10.1088/1674-1137/40/10/100001 (https://doi.org/10.1088%2F1674-1137%2F40%2F10%2F100001). ISSN 1674-1137 (https://www.worldcat.org/issn/1674-1137).
9. Giusti, D.; Lubicz, V.; Martinelli, G.; Sanflippo, F.; Simula, S. (2017). "Strange and charm HVP contributions to the muon (g-2) including QED corrections with twisted-mass fermions". *Journal of High Energy Physics*. arXiv:1707.03019 (https://arxiv.org/abs/1707.03019). doi:10.1007/JHEP10(2017)157 (https://doi.org/10.1007%2FJHEP10%282017%29157).

10. "The E821 Muon (g−2) Home Page" (http://www.g-2.bnl.gov/). Brookhaven National Laboratory. Retrieved 1 July 2014.
11. "Revolutionary muon experiment to begin with 3,200-mile move of 50-foot-wide particle storage ring" (http://www.fnal.gov/pub/presspass/press_releases/2013/Muon-g-2-201305.html) (Press release). Fermilab. 8 May 2013. Retrieved 16 March 2015.
12. Muon Magnet's Moment Has arrived (http://news.fnal.gov/2017/05/muon-magnets-moment-arrived/), Fermilab press release
13. Eidelman, S.; Passera, M. (November 2011). "Theory of the tau lepton anomalous magnetic moment". *Modern Physics Letters A*. **22** (03): 159–179. arXiv:hep-ph/0701260 (https://arxiv.org/abs/hep-ph/0701260). Bibcode:2007MPLA...22..159E (https://ui.adsabs.harvard.edu/abs/2007MPLA...22..159E). doi:10.1142/S0217732307022694 (https://doi.org/10.1142%2FS0217732307022694).

Bibliography

- Sergei Vonsovsky (1975). *Magnetism of Elementary Particles*. Mir Publishers.

External links

- Overview of the *g−2* experiment (http://www.g-2.bnl.gov/physics/index.html)
- Kusch, P.; Foley, H. M. (1948). "The Magnetic Moment of the Electron". *Physical Review*. **74** (3): 250–263. Bibcode:1948PhRv...74..250K (https://ui.adsabs.harvard.edu/abs/1948PhRv...74..250K). doi:10.1103/PhysRev.74.250 (https://doi.org/10.1103%2FPhysRev.74.250).