Preface

As the title suggests, lepton electromagnetic dipole moments, including anomalous magnetic, electric, and transition moments, are the main subject of this volume. Studies of these quantities test the Standard Model of elementary particle physics at the level of its quantum fluctuations, and search for New Physics effects.

Those searches fall into two categories. The first approach entails precision experimental measurements of the electron and muon anomalous magnetic moments, which can then be compared with theoretical Standard-Model predictions of comparable accuracy. A clear discrepancy would point to additional contributions of New Physics origin. The second approach involves searches for non-vanishing electric, and transition dipole moments (e.g. $\mu \to e\gamma$). The Standard Model predicts those quantities to be unobservably small. Hence, discovery of a non-zero value would be interpreted as direct evidence for New Physics.

The measurement and theory of the electron and muon magnetic moments has a long and distinguished history. The former was intimately intertwined with the development of quantum electrodynamics, and the calculation of the electron anomalous magnetic moment (anomaly) by Schwinger represented the very first quantum-loop computation. Its simple but elegant value is inscribed on the memorial marker located near his grave in the Mount Auburn Cemetery in Cambridge Massachusetts.

QED calculations of the electron anomaly have become an industry, with the sixth-order (3-loop) contribution having been calculated analytically by Laporta and Remiddi. The eighth- and tenth-order (4- and 5-loop) contributions have occupied a significant fraction of Kinoshita's career, and with his collaborators he continues these numerical calculations today. Meanwhile, the experiments by Gabrielse and his collaborators have reached the remarkable precision of 0.24 parts per billion on the electron anomaly, some 20 times more precise than independent measurements of the fine-structure constant α. Chapters by the above-mentioned experts, along with an historical introduction by BLR and a general overview of electromagnetic moments by A. Czarnecki and WJM, provide an up-to-date review of the status of the electron magnetic moment. We also include a brief discussion of the various measurements of α by G. Gabrielse and an article by K. Pachucki and J. Sapirstein on the theory necessary to extract α from helium fine structure. At present, the electron g-value along with the QED theory provides the best measure of α.

The relative sensitivity of the muon anomaly to higher mass scales compared to the electron goes as $(m_\mu/m_e)^2 \simeq 43,000$, which requires knowledge of the hadronic contribution arising from virtual hadrons in vacuum polarization loops (which dominate the uncertainty on the Standard-Model value of the muon anomaly), as well as the one- and two-loop contributions from the weak gauge bosons, fermions and Higgs scalar. Thus, at the present experimental precision for the muon anomaly of 0.54 ppm, there is significant sensitivity to the several-hundred GeV mass scale. The current Standard-Model prediction for the muon anomalous magnetic moment and potential effects due to New Physics are reviewed in chapters by Czarnecki and WJM; M. Davier; J. Prades, E. de Rafael and A. Vainshtein; K. Lynch; and D. Stöckinger, while its experimental status is described in a chapter by J. Miller, BLR and K. Jungmann.

Dedicated searches for electric dipole moments (EDMs) date back to the pioneering observation by Purcell and Ramsey in 1950, that a particle EDM would violate parity, but should nevertheless be searched for as a test of that symmetry. The experimental quest for an EDM of the electron, the neutron, and of atomic nuclei has become an important area in the search for physics beyond the Standard Model. The level of precision that has been reached, $< 1.6 \times 10^{-27}$ e-cm for the electron, $< 2.9 \times 10^{-26}$ e-cm for the neutron and $< 3.1 \times 10^{-29}$ e-cm for ^{199}Hg, is beginning to challenge models such as supersymmetry. There is substantial hope that the discovery of an EDM will come in the present generation of experiments. Reviews of all of these searches, along with the related theoretical issues, are covered in this volume by M. Pospelov and A. Ritz; E. Commins and D. DeMille; S. Lamoreaux and R. Golub; W.C. Griffith, M. Swallows and N. Fortson; all active experts in the field. The new idea of using storage rings to search for EDMs of charged particles is covered in a chapter by BLR, J. Miller and Y. Semertzidis.

The related process, the transition dipole moment that would permit lepton flavor (muon number) violation (LFV) in reactions such as $\mu^- \mathcal{N} \to e^- \mathcal{N}$ and $\mu^+ \to e^+ \gamma$ are complementary to the studies of electric and magnetic dipole moments. Since the Standard-Model predictions for such reactions are suppressed by $(m_\nu/M_W)^4 < 10^{-45}$ and thus experimentally unobservable, any observation of LFV in the charged sector would signal the presence of New Physics. Charged lepton transition moments due to New Physics and experimental searches are covered in the chapters by Y. Okada and Y. Kuno which complete the book.

The idea for this volume came about when after a seminar given at Imperial College, BLR was approached by an editor from Imperial College Press to write a monograph on muon physics. The counter proposal was a volume dedicated to the topics covered at the series of symposia on Lepton Moments started by Klaus Jungmann in Heidelberg in 1999 and continued by BLR on Cape Cod in 2003, 2006 and planned for 2010. We are indeed grateful that so many of our friends and colleagues have joined with us to create this volume. We gratefully acknowledge Kevin R. Lynch for his encyclopedic expertise in LaTeX, which he used to solve numerous issues in putting this document together.

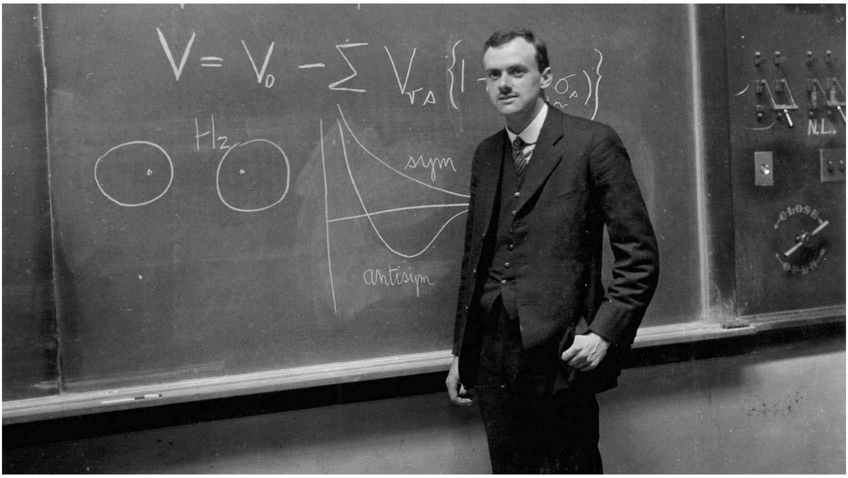
We dedicate this volume to Norman Ramsey, and to the memory of Paul Dirac, Julian Schwinger, Polykarp Kusch and Edward Purcell, all pictured on the next page, who carried out the seminal work which began our modern journey through the field of magnetic and electric dipole moments.

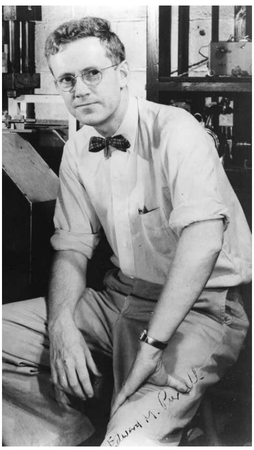
B. Lee Roberts and William J. Marciano

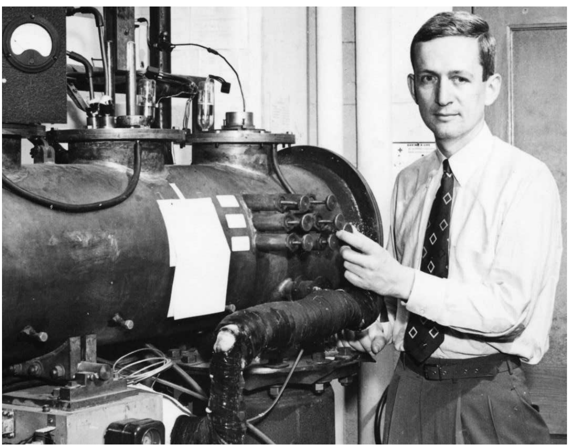
Clockwise:

Julian Schwinger,
Polykarp Kusch,
Paul Dirac,
Norman Ramsey and
Edward Purcell

Courtesy AIP Emilio
Segrè Visual Archives
(full credits overleaf)







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