Afterthoughts

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As Emilio Zavattini said in his concluding remarks, the many excellent talks covering an impressively broad range of topics given at this workshop require no summary. However, we do have some comments, which others may have considered as well, about how the aims of this field might become better understood and more widely appreciated in the physics community. Such understanding and appreciation will help insure that the resources and support needed for a healthy future will continue to be available. One example is the understanding and support needed for the important and difficult measurement of the Lamb shift in muonic hydrogen, mentioned by Zavattini in his concluding remarks.

Our principal point is that the field should make closer contact with the standard model of particle physics and with the current searches for physics beyond the standard model. We all know that many of the phenomena, whose studies have established and are testing the standard model, rely on or are related to quantum electrodynamics, which is assumed to be correct because of the many precise verifications made for QED itself. The importance of QED to the standard model should be emphasized. A prominent example is electroweak interference, first observed as parity nonconservation in polarized electron-deuteron deep inelastic scattering, and studied intensively in atomic PNC experiments. This phenomenon has played an important role in establishing the unified electroweak theory and is currently extending the sensitivity of tests of the standard model.

Several of the topics discussed at our workshop, including the electron and muon $g-2$ values, have been related to physics beyond the standard model. Most speculations about features beyond the standard model involve higher mass particles, either real or postulated. For the electron $g-2$, where the mass scale is an electron mass, the sensitivity to features beyond the standard model is expected to be small; however, for the muon $g-2$, the sensitivity should be greater by the order $(m_\mu/m_e)^2 = 4\times 10^4$, and hence an interesting test of supersymmetric theories will be provided by the on-going muon $g-2$ experiment.

Muonium, hydrogen, and positronium energy levels are also expected to be insensitive to phenomena beyond the standard model. The hyperfine structure interval $\Delta\nu$, the Zeeman effect, and the $1s-2s$ transition in muonium provide the fundamental constants m_μ, μ_μ and α which are needed in tests of the standard model. For example, the muon mass m_μ is needed for a determination of the mass of the muon neutrino, assumed to be zero in the standard model.

For hydrogen, the Lamb shift has served as a discovery leading to the development of modern quantum electrodynamics and also as a testing ground for QED theory. The interpretation of the extremely accurate measurement of the $1s-2s$ transition in H is presently limited by our knowledge of $\langle r_p^2 \rangle$. If the Lamb shift in $\mu^- p$ is measured, it will provide a value for $\langle r_p^2 \rangle$, and hence the measured $1s-2s$ transition in H can provide either a precise value for the Lamb shift or for the Rydberg constant.

A discrepancy between theory and experiment for the Lamb shift in H, D, or He^+ would initially be ascribed to lack of adequate precision in the experiment or in the theory. At this level, one might view its resolution as a challenging exercise, not a major breakthrough in understanding. It seems to us important to have some discussion of what new physics might contribute to a discrepancy in the Lamb shift. It would also be interesting to have such a discussion for the Lamb shift in a high-Z single-electron ion, where electric field strengths become enormous. In that regard it should be noted that limiting fields based on the Einstein-Infeld model of the electron were ruled out twenty years ago by comparing x-ray measurements in Fermium with calculations of the $1s$ Lamb shift. Clearly, explanations based on new physics for any discrepancy must be consistent with all of our other knowledge.

The goal of precision antihydrogen spectroscopy is motivated as a bold search for CPT violation, which might be regarded as a search for physics beyond, beyond the standard model.

In summary, we think that although the results presented at this workshop were impressive, the importance of our research to the development of modern physics would be more obvious to other physicists if we placed stronger emphasis on the relation of our experiments and calculations to the standard model and to the search for physics beyond the standard model.