What Can Be Tested in Quantum Electrodynamics?\textsuperscript{1}

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In this paper we examine the theoretical foundations underlying the testing of quantum electrodynamics. We show that for the photon propagator (together with the contiguous vertices) it is not necessary to introduce ad hoc modifications in sufficiently accurate scattering experiments. Energy, momentum transfer, and accuracy determine the tested length in a model-independent way. The situation is quite different with the electron propagator. If gauge invariance is taken for granted, the electron propagator cannot be tested with processes where diagrams with open electron lines are important in the lowest order of perturbation theory. These processes can only give limits for anomalous moment and multiphoton parts of the vertices. On the other hand, processes with closed electron loops (vacuum polarization), such as photon–photon and Delbrück scattering, as well as photon splitting or corresponding low-energy, high-precision experiments can give limits also for the electron propagator. But in these cases only less accurate limits can be obtained, which depend on the modification model. Hence testing of the electron propagator, i.e., roughly speaking, the Dirac equation, is much more difficult than testing of the photon propagator, i.e., Maxwell’s equations.

1. INTRODUCTION

In recent years the principles of quantum electrodynamics (QED) have been applied very successfully to other fields, e.g., gauge theories of weak and strong interactions. Perhaps even a complete theory of all interactions, including gravitation, could be based on these principles. It is therefore very important to test QED as accurately as possible. But in spite of the considerable effort necessary to do such experiments, the theoretical conseq-

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Dedicated to the memory of Prof. Wolfgang Yourgrau (1908–1979).
quences have been dealt with in a rather crude way. It may therefore be worthwhile to explore the question, What can really be tested in qed?

In qed Maxwell's and Dirac's equations are coupled in the so-called minimal way with the field quantities interpreted as operators. Then perturbation theory is used for solving the equations. In this step, renormalization must be used. Renormalization introduces, however, no new ingredients into the theory, since in qed it only means that all parts of mass and charge must be taken together to give the observable quantities, as is well known. Even if all of these parts were finite, one would have to renormalize in qed. The theory now consists of all Feynman diagrams described by the propagators of the photon, the electron, and the vertex operator. These three quantities are the elementary constituents which build up any matrix element in any order. However, photon and electron propagators are always multiplied with the contiguous vertices. That is, roughly speaking, only two of these three elementary constituents are observable. This situation is already inherent in classical electrodynamics. We never can distinguish between a deviation from Coulomb's law and an extended charge distribution.

2. TESTING OF THE PHOTON PROPAGATOR

We will consider first the simplest case, this is, electron–electron scattering. Here we can restrict our considerations to the lowest order (Fig. 1). Radiative corrections are subtracted from the experimental results before the comparison with the theory, because they depend critically on the experimental arrangement and so far are considerably smaller than the first order. The photon propagator $D$ is given in perturbation theory by (apart from constant factors)

$$D(q^2) = \frac{1}{q^2}$$  \hspace{1cm} (1)

Fig. 1. Diagrams for electron–electron scattering in the lowest order.