Quantum uncertainty of light fields and energy quantization – how comes light is best described by operators and what does this mean?

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Classical electromagnetism describes the vast majority of experimental observations made on light in a very satisfactory manner. However, some observations reveal very peculiar phenomena, which cannot be described in this classical way. We start by reviewing these observations and then use them as a starting point in order to motivate and derive the modern quantum description of light. In particular, we will find that Maxwell's equations combined with the experimental observation that the light field is always uncertain, inevitably leads to the introduction of field operators, i.e. the creation and annihilation operators, and the quantization of energy. Field uncertainty and energy quantization are two sides of the same coin. Consequently, there are two complementary ways to describe the quantum light field: (1) the field quadratures and their distribution in phase space, and (2) the energy levels and the corresponding eigen functions. The first way is called the continuous variable description and the second way the discrete variable description. Any quantum light field can be described in either way, but often in a given specific case one way is more efficient and appropriate than the other one. Examples will be discussed.