Elementary particles in an introductory course on quantum mechanics

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Abstract. I review popular definitions of elementary particles and argue that their description as excitations of quantum fields has its place in an introductory course on quantum mechanics at universities and can be further simplified to satisfy curiosity of motivated high school students.

Extended abstract

Elementary particles are the basic building blocks of matter. They determine the structure and properties of various substances at both microscopic and macroscopic levels. Particles are typically both quantum and relativistic objects and thus the proper framework for their description is quantum field theory. There are, however, good reasons for a chapter on elementary particles in an introduction to quantum mechanics (IQM). First, complex topics should be explained in several brushstrokes, each bringing finer details, and IQM provides a proper setting for the first one. Second, a quantum field theory course is usually taken by particle physics majors but for many other science and engineering students IQM is the only course on quantum physics. We would miss a good opportunity if we did not try to tell them what the basic building blocks of nature are according to modern science. This question is, in fact, not an easy one.

If we asked ten physicists what a particle is, we might get ten different answers, including a) a particle is what we see in the detector, b) a point-like object with mass and various charges, c) a collapsed wave function, d) an excitation of a quantum field or perhaps e) a representation of the Poincare group. The first two definitions are simple to understand even for high school students but may be viewed as not quite satisfactory since they raise many questions about the theoretical picture of the particle. Option c) is, in fact, a routine part of IQM and rightly so. Answers d) and e), although accurate, seem technically involved for an introductory course. We thus face a difficult choice of simplifying our explanation at the expense of accuracy.

I this contribution I will review strengths and weaknesses of each of the five definitions and argue for the option d), as the one offering a viable path from ‚what we see in the detector‘ to the correct picture of the particles according to today‘s physics: excitations or waves in quantum fields . I assume the students are familiar with a classical harmonic oscillator and travelling and standing waves. Other prerequisites such as the wave properties of particles, wave packets, wavefunctions , and quantum harmonic oscillator, they learn during the course.

Using electromagnetic field as an example, I will show how we might picture a photon spin as a circular flow of momentum generated by the circularly polarized photon. Further, showing that a free electromagnetic field is equivalent to a set of harmonic oscillators, we can easily quantize the field and arrive at a visualization of a single photon as a wave of the minimum energy and minimum mean amplitude allowed by quantum mechanics - the quantum of electromagnetic field. I will argue that there is a potential to simplify this picture for the benefit of motivated high school students.