Abstract The determination of the fine structure constant $\alpha$ and the search for its possible variation are considered. We focus on the role of the fine structure constant in modern physics and discuss precision tests of quantum electrodynamics. Different methods of a search for possible variations of fundamental constants are compared and those related to optical measurements are considered in detail.

Keywords Fine structure constant · Quantum electrodynamics · Violation of Lorentz invariance · Gravitational constant

1 Introduction

Fundamental constants play an important role in modern physics. Some of them are really universal and enter equations from different subfields. An example is the fine structure constant $\alpha$ and other quantities related to properties of electron and nucleon. Electron is a carrier of the electric charge and it is the orbiting particle in any atom. Thus, its characteristics enter a great number of basic equations of atomic physics as well as various effects of electrodynamics, which are related to quantum nature of physics or discrete (atomic) nature of matter. The latter is a back door through which quantum physics enters nearly classical experiments involving the Avogadro number, Faraday constant and various properties of single species. The “hidden” quantum mechanics is in the fact of the very existence of identical objects. Thus, the electron charge $e$ is a mark of an open or hidden quantum nature of a phenomenon.

Most quantities related to properties of the electron are dimensional and thus depend on our definitions of units. The fine structure constant, which in fact is the
squared electric charge of electron in natural units

\[ \alpha = \frac{e^2}{4\pi \epsilon_0 h c}, \]

is dimensionless and thus its value is a “true” fundamental constant which does not depend on any conventions (like, e.g., definitions of units in International System SI) and it is one of very few fundamental constants which can be measured in actual physical experiments and originate from physics of very short distances related to Grand Unification Theories.

Protons as well as nuclei formed by protons and neutrons also transport electric charge in some phenomena and they are chiefly responsible for the mass of classical massive objects. As attractors for orbiting electrons, nuclei are responsible for recoil and hyperfine effects. They also offer some dimensionless parameters such as mass ratio of electron and proton \( \frac{m_e}{m_p} \) and \( g \) factors of free proton and neutron. However, such parameters are less fundamental than the fine structure constant.

A variety of completely different approaches to an accurate determination of the fine structure constant \( \alpha \) shows how fundamental and universal this constant is. The value of \( \alpha \) can be determined from quantum electrodynamics (QED) of a free electron, from spectroscopy of simple atoms, from quantum nonrelativistic physics of atoms and particles, from measurement of macroscopic quantum effects with help of electrical standards. A comparison of different approaches to the determination of the fine structure constant allows us to check consistency of data from all these fields, where the determination of \( \alpha \) involves the most advanced methods and technologies. The further output of this activity is precision QED tests and the new generation of electrical standards.

Time and space variations of some fundamental constants are very likely for a number of reasons. For example, if we accept a so-called inflationary model of the evolution of our Universe then we have to acknowledge a dramatic variation of the electron mass and electron charge at a very early moment of the evolution of the Universe. Therefore we could expect some much slower variations of these and some other quantities at the present time.

Possible time (and space) variations of the values of the fundamental constants are sometimes related to a violation of local time (and, in a more general case, position) invariance (generally called local position invariance, LPI), which is a part of the symmetry related to special and general relativity. Various gravitational theories suggesting such a violation are under theoretical consideration now. LPI implies that the values of the fundamental constants do not depend upon when and where they were measured, so vice versa, varying constants would violate LPI.

A possible variation of fundamental constants is searched for in two kinds of experiments:

- measurements of quantities which are easily accessible and/or potentially highly sensitive to the variations (such as experiments at the Oklo reactor);
- studies of the quantities that allow a clear interpretation, particularly in terms of fundamental physical constants.

Indeed, the mere fact of a cosmological variation detected today and determination of its magnitude would be a great discovery and one could think that its clear interpretation is not so important at the initial stage of a search.