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Paper Authors:
Saidov Safo Olimovich[1], Makhmudov Sanjar Ikhtiyor ugli[2]

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Microcosm - from the atom of Democritus to quarks

Saidov Safo Olimovich[1], Makhmudov Sanjar Ikhtiyor ugli[2]

Associate Professor of the Department of Physics, Bukhara State University, Candidate of Chemical Sciences, Bukhara, Uzbekistan[1]
Master student of the Department of Physics, Bukhara State University, Bukhara, Uzbekistan[2]
e-mail: safo.saidov.64@mail.ru

Abstract: This article is a continuation of the work on the study of scientific and educational-methodological aspects of the theory of the structure of the microcosm. The article presents the history of the development of atomism since the time of Democritus, the development of the ideas of atomism and the study of elementary particles, in the set of elementary particles to establish some order, hierarchy.

Keywords: Ancient philosophy, Democritus, atom, atomism, elementary particles, radioactivity, electron, alpha particles, atomic model, nucleus, Bohr's postulates, electron charge density, particle lifetime, proton, neutrino, quantum numbers, photons, mesons, rest mass, leptons, muon, tau - particle, quarks, gluons.

Introduction

This work is a continuation of a series of publications on the study of scientific, educational and methodological aspects of the theory of the structure of the microworld [1-3].

During the development of ancient philosophy, the first atomistic teachings of Democritus were created. Atomists believed that everything in the world consists of the smallest, then indivisible particles - atoms. Democritus created the first most famous atomistic doctrine, in which he offered his understanding of the structure of nature. He believed that there are atoms and emptiness, all things consist of the smallest unchanging, eternally existing particles (atoms), which are unlimited in number. Atoms have a certain weight, shape, volume. Atoms move in different directions. Earth, water, air, fire are the primary groupings of atoms. Combinations of atoms form whole worlds: in an infinite space, there are an infinite number of worlds. Atoms are homogeneous, indivisible and immutable. There are atoms of matter, atoms of space (amers), atoms of time (chronons). Each body consists of a certain number of atoms, each of which has a finite volume, therefore the body has a finite volume. Man is also a collection of atoms. The human soul is composed of special atoms ..... [4,5].

Since the time of Democritus, many years and centuries have passed, science, technology have developed, and worldviews in the field of the structure of matter, elementary particles have developed. At the beginning of the twentieth century, scientists realized that atoms are composed of other, more elementary particles. By 1932, it was established that the nuclei of atoms contain positively charged protons and chargeless neutrons, and that the charge of protons in neutral atoms counterbalances the negatively charged light electrons. It would seem that the picture of the world has acquired a completely finished form. However, in 1932, a positron was discovered, which is an "anti-electron", in 1944, when only seven elementary particles were known, Vitaly Lazarevich Ginzburg wrote in the journal Science and Life: “Physicists are even beginning to talk about an excessive abundance of elementary particles - there are too many of them. " In subsequent years, discoveries in this area followed one another. Then elusive neutrinos, mysterious mesons, bosons appear ... And in the 1960s it becomes obvious: protons and neutrons are also not elementary! They are made up of quarks, which are difficult to see and imagine. What is the picture of the world through the prism of elementary particle physics now? There is a unique and original story about this by Academician V.A. Matveev, Director of the Institute for Nuclear Research, Russian Academy of Sciences [6].

In physics, the concept of atoms as the last indivisible structural elements of matter came from chemistry. Physical studies of the atom proper began at the end of the 19th century, when the French physicist A.A. Becquerel discovered the phenomenon of radioactivity, which consisted in the spontaneous transformation of atoms of some elements into atoms of other elements. The study of radioactivity was continued by the French physicists, spouses Pierre and Marie Curie, who discovered new radioactive elements polonium and radium.

The history of the study of the structure of the atom began in 1897 thanks to the discovery by J. Thomson of the electron - a negatively charged particle that is part of all atoms. Since electrons have a negative charge, and the atom as a whole is electrically neutral, an assumption was made about the presence, in addition to the electron, of a positively charged particle. According to calculations, the mass of an electron was 1/1836 of the mass of a positively charged particle - a proton. Proceeding from the huge, in comparison with the electron, mass of a positively charged particle, the English physicist W. Thomson (Lord Kelvin) proposed in 1902 the first model of the atom - a positive charge is distributed over a sufficiently large region, and electrons are interspersed into it, like "raisins in pudding". This idea was developed by J. Thomson. J. Thomson's model of the atom, on which he worked for almost 15 years, could not resist experimental verification.

In 1908 E. Marsden and H. Geiger, collaborators of E. Rutherford, conducted experiments on the passage of alpha particles through thin plates of gold and other metals and found that almost all of them pass through the plate, as if there were no obstacles, and only 1 / 10,000 of them are strongly rejected. It was not possible to explain this by J. Thomson's model, but E. Rutherford found a way out. He drew attention to the fact that most of the particles are deflected at a small angle, and a small part - up to 150 °. E. Rutherford came to the conclusion that they hit some kind of obstacle, this obstacle is the nucleus of an atom - a positively charged microparticle, the size of which (10-12 cm) is very small compared to the size of the atom (10-8 cm), but the mass of the atom is almost completely concentrated in it.

The model of the atom, proposed by E. Rutherford in 1911, resembled the solar system: in the center there is an atomic nucleus, and electrons move around it in their orbits. The nucleus has a positive charge, while the electrons are negative. Instead of the gravitational forces acting in the solar system, electric forces act in the atom. The electric charge of the nucleus of an atom, numerically equal to the ordinal number in the periodic system of Mendeleev, is balanced by the sum of the charges of electrons - the atom is electrically neutral. The insoluble contradiction of this model was that electrons, in order not to lose stability, must move around the nucleus. At the same time, according to the laws of electrodynamics, they must necessarily emit electromagnetic energy. But in this case, the electrons would very quickly lose all their energy and fall onto the nucleus.

The next contradiction is associated with the fact that the emission spectrum of an electron must be continuous, since an electron, approaching the nucleus, would change its frequency. Experience shows that atoms emit light only of certain frequencies. That is why atomic spectra are called line spectra. In other words, Rutherford's planetary model of the atom turned out to be incompatible with JK Maxwell's electrodynamics.

In 1913, the great Danish physicist N. Bohr applied the principle of quantization in solving the problem of the structure of the atom and the characteristics of atomic spectra.

N. Bohr's model of the atom was based on the planetary model of E. Rutherford and on the quantum theory of the structure of the atom developed by him. N. Bohr put forward a hypothesis of the structure of the atom, based

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on two postulates that are completely incompatible with classical physics:

1) in each atom there are several stationary states (in the language of the planetary model, several stationary orbits) of electrons, moving along which an electron can exist without emitting;

2) when an electron passes from one stationary state to another, the atom emits or absorbs a portion of energy.

Bohr's postulates explain the stability of atoms: electrons in stationary states do not emit electromagnetic energy without an external reason. It becomes clear why the atoms of chemical elements do not emit radiation if their state does not change. The line spectra of atoms are also explained: each line of the spectrum corresponds to the transition of an electron from one state to another.

N. Bohr's theory of the atom made it possible to give an accurate description of the hydrogen atom, consisting of one proton and one electron, which is in good agreement with experimental data. The further extension of the theory to many-electron atoms and molecules ran into insurmountable difficulties. The more detailed the theoreticians tried to describe the motion of electrons in the atom, to determine their orbits, the greater the discrepancy between the theoretical results and experimental data. As it became clear in the course of the development of quantum theory, these discrepancies were associated mainly with the wave properties of the electron. The wavelength of an electron moving in an atom is approximately 10-8 cm, i.e. it is of the same order of magnitude as the size of an atom. The motion of a particle belonging to any system can be described with a sufficient degree of accuracy as the mechanical motion of a material point along a certain orbit (trajectory) only if the wavelength of the particle is negligible in comparison with the size of the system. In other words, it should be borne in mind that an electron is not a point or a solid ball, it has an internal structure that can change depending on its state. In this case, the details of the internal structure of the electron are unknown. Consequently, it is fundamentally impossible to accurately describe the structure of an atom based on the concept of the orbits of point electrons, since such orbits do not actually exist. Due to their wave nature, electrons and their charges are, as it were, smeared over the atom, but not uniformly, but in such a way that at some points the time-averaged electron charge density is higher, and at others it is lower.

The description of the distribution of the density of the electronic charge was given in quantum mechanics: the density of the electronic charge at certain points gives a maximum. The curve connecting the points of maximum density is formally called the electron orbit. The trajectories calculated in the theory of N. Bohr for one electron hydrogen atom coincided with the curves of the maximum average charge density, which determined the agreement with the experimental data.

N. Bohr's theory is, as it were, a borderline of the first stage in the development of modern physics. This latest effort is to describe the structure of the atom on the basis of classical physics, supplemented with only a small number of new assumptions. The postulates introduced by Bohr clearly showed that classical physics is unable to explain even the simplest experiments related to the structure of the atom. Postulates, alien to classical physics, violated its integrity, but only allowed to explain a small circle of experimental data.

The impression was created that N. Bohr's postulates reflect some new, unknown properties of matter, but only partially. The answers to these questions were obtained as a result of the development of quantum mechanics. It turned out that N. Bohr's atomic model should not be taken literally, as it was in the beginning. In principle, processes in an atom cannot be visualized in the form of mechanical models by analogy with events in the macrocosm. Even the concepts of space and time in the form existing in the macrocosm turned out to be inappropriate for describing microphysical phenomena. The atom of physicists - theorists more and more became an abstractly unobservable sum of equations.

Further development of the ideas of atomism was associated with the study of elementary particles. The particles that make up the previously "indivisible" atom are called elementary. These include those particles that are obtained under the conditions of an experiment on powerful accelerators. More than 350 microparticles have been discovered so far. The term "elementary particle" originally meant the simplest, further indecomposable particles that underlie any material formations. Later physicists realized the whole conventionality of the term "elementary" in relation to micro-objects. Now there is no doubt that the particles have this or that structure, but nevertheless the historically established name continues to exist.

The rest mass of elementary particles is determined in relation to the rest mass of the electron. There are elementary particles that have no rest mass - photons. The rest of the particles on this basis are divided into: leptons - light particles (electron and neutrino); mesons - average particles with a mass ranging from one to a thousand electron masses; baryons are heavy particles whose mass exceeds a thousand electron masses and which include protons, neutrons, hyperons and many resonances.

Electric charge is another important characteristic of elementary particles. All known particles have a positive, negative or zero charge. Each particle, except for a photon and two mesons, corresponds to antiparticles with the opposite charge. In 1967, the American physicist M. Gell-Mann put forward a hypothesis about the existence of quarks - particles with a fractional electric charge.

According to their lifetime, particles are divided into stable and unstable. There are five stable particles: a photon, two types of neutrinos, an electron and a proton. It is the stable particles that play the most important role in the structure of macrobodies. All other particles are unstable, they exist for about 10-10 - 10-24 seconds, after which they decay.

The main characteristics of elementary particles are mass, charge, average lifetime, spin and quantum numbers.

In addition to charge, mass and life time, elementary particles are also described by concepts that have no analogues in classical physics: the concept of "spin", or the proper angular momentum of a microparticle, and the concept of "quantum numbers", which expresses the state of elementary particles. According to modern concepts, all elementary particles are divided into two classes: fermions (named after E. Fermi) and bosons (named after S. Bose). Fermions include quarks and leptons, bosons - field quanta (photons, vector bosons, gluons, gravitinos and gravitons). These particles are considered to be truly elementary, i.e. further indecomposable. The rest of the particles are classified as conditionally elementary, i.e. compound particles formed from quarks and corresponding field quanta. Fermions make up matter, bosons carry interactions. Elementary particles are involved in all kinds of known interactions. Advances in the study of elementary particles contributed to the further development of the concept of atomism.

Currently, it is believed that among the many elementar particles, 12 fundamental particles and the same number of antiparticles can be distinguished. Six particles are quarks with exotic names: "up", "down", "charmed", "strange", "true", "adorable". The remaining six are leptons: an electron, a muon, a tau - a particle and the corresponding neutrinos (electron, muon, tau - neutrinos). These 12 particles are grouped into three generations, each with four members.

In the first generation - "up" and "down" quarks, an electron and an electron neutrino.

In the second generation - "charmed" and "strange" quarks, muon and muon neutrino.

In the third generation - "true" and "lovely" quarks and tau particles with their own neutrinos [7].

It is assumed that the rest of the generations can be created artificially on particle accelerators. Based on the quark model, physicists have developed a simple and elegant solution to the problem of the structure of atoms. Each atom consists of a heavy nucleus (strongly bound by the gluon fields of protons and neutrons) and an electron shell. The number of protons in the nucleus is equal to the ordinal number of the element in the periodic table of chemical elements of D.I. Mendeleev. The proton has a positive electric charge, the mass is 1836 times the mass of the electron, the dimensions are about 10-13 cm. The electric charge of the neutron is zero. The proton, according to the quark hypothesis, consists of two "up" quarks and one "down" quark, and the neutron consists of one "up" and two "down" quarks. They cannot be represented as a solid ball, rather, they resemble a cloud with blurred boundaries, consisting of virtual particles that are born and disappear.

There are still questions about the origin of quarks and leptons, about whether they are the main particles of nature and how fundamental. The answers to these questions are sought in modern cosmology. Of great importance is the study of the creation of elementary particles from the vacuum, the construction of models of primary nuclear fusion that gave rise to certain particles at the moment of the birth of the Universe.

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