

# WHAT'S INSIDE THE PROTON

THE INVISIBLY OBVIOUS

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*Written by: Ofer Comay*

*Scientific advisor: Eliyahu Comay*

*Editor: Addie Ney*



*“Even now, two decades after QCD was formulated, little is known from first principles about the structure of the proton, neutron and other hadrons.”*

*Robert L. Jaffe, 1995<sup>1</sup>*

*“The proton is complicated, but it is a very, very important object in our lives. It is unsatisfying intellectually that we cannot understand how the inside of the proton behaves.”*

*Emlyn W. Hughes, 1997, about the proton spin crisis<sup>2</sup>*

*“If the results are not a statistical fluke, new physics has been observed. One possibility is that our understanding of what’s inside the proton is somehow wrong.”<sup>3</sup>*

*Frank Sciulli , 1997, about DESY experiments*

*“The results are in complete disagreement with the calculations... We are not aware of any published detailed prediction presently available which can explain the behaviour of these data.”<sup>4</sup>*

*J.J. Aubert et al., 1983, about the 1st EMC effect*

*“Ironically, from the perspective of QCD, the foundations of nuclear physics appear distinctly unsound.”*

*Frank Wilczek, 2007, about QCD vs. the strong nuclear force<sup>5</sup>*

*“Currently, the color van der Waals force does not seem to be a correct model for nuclear interaction without modifications.”*

*S. S. M. Wong, 1998, about QCD vs. the strong nuclear force<sup>6</sup>*

*“No direct translation between the Standard Model and VMD has yet been made.”*

*H.B. O’Connell, B.C. Pearce, A.W. Thomas and A.G. Williams, 1997, About the hadronic properties of the photon<sup>7</sup>*

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<sup>1</sup> Physics Today, 1995

<sup>2</sup> Science News, Sept 6, 1997 by Ivars Peterson

<sup>3</sup> Columbia University News, 1997

<sup>4</sup> J.J. Aubert *et al.*, Phys. Lett. **123B**, 275 (1983)

<sup>5</sup> Frank Wilczek, *Hard-core revelations*, NATURE, Vol. **445** 156 (2007).

<sup>6</sup> S. S. M. Wong, *Introductory Nuclear Physics*, (Wiley, New York, 1998). p.102

<sup>7</sup> H.B. O’Connell, B.C. Pearce, A.W. Thomas and A.G. Williams, *Rho-omega mixing, vector meson dominance and the pion form-factor*, Prog. Nucl. Part. Phys. 39 (1997) 201-252

*“The whole story – the discoveries themselves, the tidal wave of papers by theorists and phenomenologists that followed, and the eventual “undiscovery” – is a curious episode in the history of science.”*

*C.G. Wohl (LBNL), a review about the search after the Pentaquarks, 2008<sup>8</sup>*

*“No strangelets were found in the experiment.”*

*K. Han, a report about the search for stable Strange Quark Matter in lunar soil<sup>9</sup>*

*“If you see nothing, in some sense then, we theorists have been talking rubbish for the last 35 years.”*

*John Ellis, about the search for the Higgs Boson in LHC, 2007<sup>10</sup>*

*“There are many students who have never seen data; I don’t know how much longer we can keep going like that.”*

*Michelangelo Mangano, about LHC experiment, 2007<sup>11</sup>*

*“It will probably be the end of particle physics.”*

*Martinus Veltman, about a scenario in which the Higgs fails to show up at the LHC, 2008<sup>12</sup>*

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<sup>8</sup> C.G. Wohl (LBNL), *Pentaquarks*, 2008. [pdg.lbl.gov/2009/reviews/rpp2009-rev-pentaquarks.pdf](http://pdg.lbl.gov/2009/reviews/rpp2009-rev-pentaquarks.pdf)

<sup>9</sup> K. Han et al., *Phys. Rev. Lett.* 103, 092302 (2009)

<sup>10</sup> The New York Times, 2007, [www.nytimes.com/2007/05/15/science/15cern.html](http://www.nytimes.com/2007/05/15/science/15cern.html)

<sup>11</sup> *Ibid.*

<sup>12</sup> [www.lindau-nobel.org/upload/Web\\_As\\_LHC\\_Draws\\_Nigh\\_\\_Nobelists\\_Outline\\_Dreams\\_\\_And\\_Nightmares\\_\\_02\\_07\\_1474.pdf](http://www.lindau-nobel.org/upload/Web_As_LHC_Draws_Nigh__Nobelists_Outline_Dreams__And_Nightmares__02_07_1474.pdf)



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# **PREFACE**



## **About this book**

Eliyahu Comay is a theoretical physicist who has published scientific articles in the areas of particle physics, quantum mechanics, nuclear physics and electromagnetism.

Many of his articles discuss fundamental issues. In 1987 Comay showed that the electric Aharonov-Bohm effect cannot occur since it violates energy conservation.<sup>13</sup> Indeed, this part of the effect predicted by Aharonov and Bohm in 1959,<sup>14</sup> was not discovered.<sup>15,16,17</sup> In another issue, Comay provided a consistent explanation<sup>18</sup> to the “hidden momentum” problem, a paradox presented by Shockley and James about thirty years earlier.<sup>19</sup>

Comay’s main discoveries were not accepted by mainstream physicists. During the last thirty years he published many scientific articles which establish a new model of the strong interaction. His model contradicts the currently accepted model, called quantum chromodynamics (QCD). This book brings the main points of the model in a language that can be understood by particle physicists as well as readers who understand physics at the level of popular science.

Physicists in the 21st century have good reasons why they refrain from considering new theories that contradict apparently “well established theories.” The justification of this approach has two levels:

- There are so many “proofs” of mainstream physical theories that the probability of a mistake is very low.
- It might be very difficult and exhausting to get into the details of a new theory and find whether it is valid or not.

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<sup>13</sup> E. Comay, *Further comments on the original derivation of the electric Aharonov-Bohm effect*, Physics Letters **A120** 196, (1987).

<sup>14</sup> Y. Aharonov and D. Bohm, *Significance of electromagnetic potentials in quantum theory*, Physical Review **115**, 485–491 (1959).

<sup>15</sup> E.g.: “...there isn’t any direct experimental observation of the electric AB effect...” A.V. Ghazaryan, K. Mouloupoulos, A. P. Djotyan and A. A. Kirakosyan, *Investigation of the electric Aharonov-Bohm effect in a quantum ring, 50 years of the Aharonov-Bohm effect*, Tel-Aviv University, 2009.

<sup>16</sup> “The existence of electric Aharonov-Bohm effect, that has not been confirmed experimentally, is a very controversial issue.” *The Electric Aharonov-Bohm Effect*, Ricardo Weder, 2010. arxiv.org/abs/1006.1385

<sup>17</sup> Batelaan, A.; Tonomura, A. (Sept. 2009). *The Aharonov-Bohm effects: Variations on a Subtle Theme*, Physics Today: 38-43.

p.41: “Thus far such experiments, crucial as they are to the characterization of the AB effects, have remained out of reach. Nor has the pulsed version of the original (Type I) electric AB effect have been performed.”

<sup>18</sup> E. Comay, *Exposing “hidden momentum,”* American Journal of Physics, 1028-1034 (1996).

<sup>19</sup> W. Shockley and R.P. James, “Try Simplest Cases” *Discovery of “Hidden Momentum” Forces on “Magnetic Currents,”* Phys. Rev. Letters **18**, 876 (1967).

In this book I try an approach that aims to remove these “built-in” obstacles. The first unit of the book, “Puzzling Experimental Results,” presents only well-known facts that were published in mainstream physics textbooks and journals during the previous century.

This unit doesn’t discuss any new model.

Particle physicists should be able to read this part within 30-45 minutes. Following this less-than-one-hour-effort, many will no longer consider QCD as a “well established theory.” It is not only that this part includes a large set of unexplained experimental results. It is the nature of these well established phenomena that would make almost any reader very skeptical about QCD foundations. I believe that after completing this relatively easy effort, many of you will be able to construct parts of Comay’s model by yourselves.

Another set of arguments why any such attack is a-priori futile is the fit of experimental findings to QCD. Such arguments were collected via long interviews with particle physics experts, and by consulting the relevant scientific literature. A response to these arguments is provided in one of the concluding chapters – “And Yet, Why Do Scientists Believe in QCD?”

Particle physicists who wish to dive deeper into the issue may find abstracts of selected articles in the last appendix of this book. My advice is to read first the book in order to have an idea about the context of the articles. Undergraduate students and science lovers may consult the appendix “terminology” for definitions of physical terms that appear inside the book.

Enjoy the reading.

Ofer Comay, Tel Aviv, March 2011

# **UNIT 1: PUZZLING EXPERIMENTAL RESULTS**



## **Chapter 1: An Invitation to Solve a Mystery**

This book discusses the structure of some of the most basic constituents of matter, called hadrons, and one of the basic forces, the strong interaction, that operates at its most elementary level. The goal of this book is to bring this subject to the awareness of as large a public as possible. This is not simple, because issues related to this field have always been inaccessible to the general public, and even to most scientists, including physicists. Most people who are interested in the field lack the capacity to distinguish between a reasonable and an unreasonable theory.

As you read this book, you will realize that a central part of today's physics is seriously challenged.

Physicists might argue that you need to study this material in depth, for at least two years, before you can distinguish between what is true and what is false in this field.

Let us carry out a short test. In this chapter you will become familiar with nearly ten unsolved problems in physics. If you have a good understanding of "high school physics," then even without any previous knowledge of these issues, you will discover on your own the key idea which solves many of these problems.

Sound crazy? Just concentrate while you read through several pages containing somewhat technical descriptions of well-known experimental facts. Most of them are considered to be unsolved mysteries in physics.<sup>20</sup>

Ready? Let's begin.

### **The basics**

The atom has a nucleus, which is surrounded by shells of electrons. Electrons have a negative electric charge and repel each other, while they are attracted to the positively charged protons within the atomic nucleus. This force is called "electromagnetic force."

The force holding molecules (and atoms of noble gas) together inside a liquid droplet is called the "van der Waals force," named for the Dutch physicist. The van der Waals force is weaker than the force that holds electrons in neutral atoms and molecules. Thus, as temperature increases, most liquids evaporate before the molecular structure is broken.

Consider the simplified illustrations below: the term "simplified" means that the particles are illustrated as "balls," which they are not, and the size of the nucleus is greatly exaggerated.<sup>21</sup>

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<sup>20</sup> The "Terminology" appendix explains the meaning of some of the physical terms used herein. Most subjects described in this book contain reference to their scientific origin.

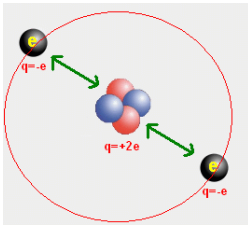


Figure 1. A simplified illustration of the electromagnetic forces operating between electrons and atomic nucleus

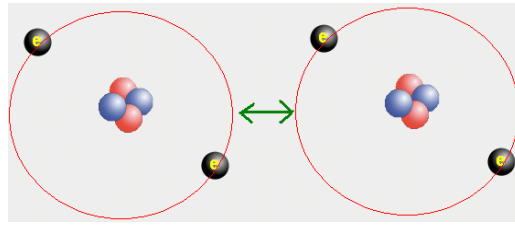


Figure 2. A simplified illustration of van der Waals forces operating between two helium atoms. See explanation later.

\* Here and later, red balls denote protons and blue balls neutrons.

An experiment conducted at the Stanford Linear Accelerator Center during the late 1960s and early 1970s demonstrated that every nucleon (proton or neutron) is composed of three valence quarks located in its external shell. A significant result of these experiments is that these quarks account only for about one half of the nucleon’s mass.<sup>22,23</sup> According to today’s dominating theory, quantum chromodynamics (QCD), the other portion of the mass is carried by particles which cannot be directly detected, called “gluons.” QCD claims that gluons exist inside the nucleon and “glue” the quarks together. For now, let’s leave this claim in question.

The force holding the quarks together is called the “strong interaction.”

The force holding nucleons inside the atomic nucleus is called the “strong nuclear force.”

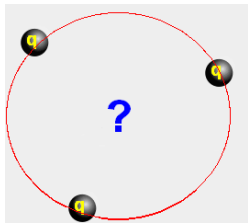


Figure 3. Strong interaction between quarks inside a nucleon

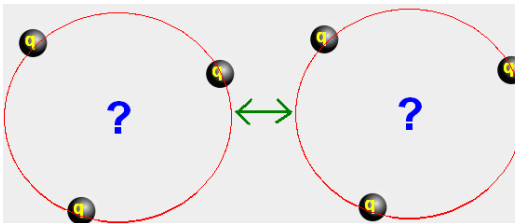


Figure 4. Strong Nuclear Force between two nucleons

The van der Waals force and the strong nuclear force share some interesting features.

### Residual forces that vanish at distance

Two of the fundamental forces in physics, the electromagnetic and gravitational forces, operate between bodies, and their intensity decreases gradually as the bodies recede from each other. Unlike these forces, the van der Waals force, acting between neutral molecules, has a particular feature: when

<sup>21</sup> Quantum mechanics assigns wave function to every particle, and the figure shows the electrons as if they were localized like in the Bohr atomic model.

<sup>22</sup> H. Frauenfelder and E. M. Henley, *Subatomic Physics*, (Prentice Hall, Englewood Cliffs 1991) p.153

<sup>23</sup> D. H. Perkins, *Introduction to High Energy Physics*, (Addison-Wesley, Menlo Park, CA 1987) p. 282

the molecules are far apart from each other, the force cancels out rapidly and practically vanishes. It is active only when the molecules are close to each other. This behavior is totally different from the common interaction pattern of the fundamental forces mentioned above.

How does this happen?

Practically, non-ionized atoms and molecules appear to be neutral when measured at a distance. Here, the fields of the positively charged nuclei and the negatively charged electrons cancel each other. This is known as the “screening effect.”

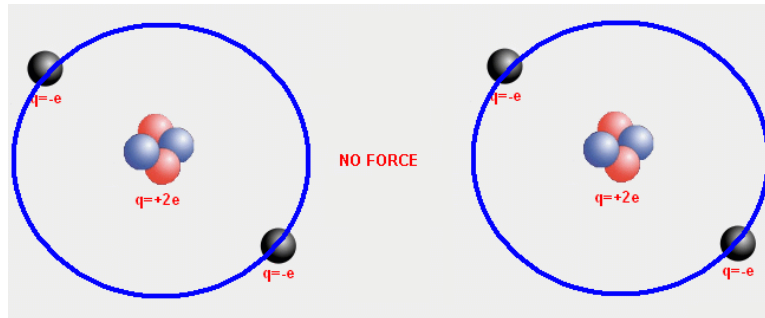


Figure 5. A simplified illustration of the “screening effect” in a pair of helium atoms (containing two electrons each). The nuclear and electronic fields cancel each other when the atoms are not too close.

But when the molecules get close to each other, the electrons in the external shells of one molecule “sense” the electric charge in the neighboring molecule and charge distribution varies. Thus, at appropriate temperatures, the van der Waals force is strong enough to hold the molecular cluster in a liquid state.

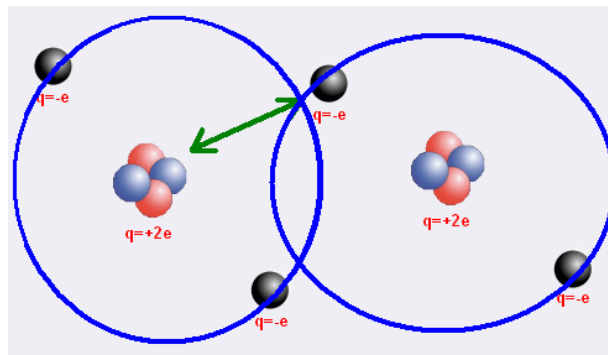


Figure 6. Van der Waals force between pair of 2-electron atoms (He). Electrons of one atom are attracted by the neighboring atomic nucleus.

Similarly, the force holding the nucleons together, the strong nuclear force, is indeed very strong, but it is quite small in comparison to the strong interaction holding the quarks together inside the nucleon. Furthermore, as the two nucleons move away from one another, the strong nuclear force ceases to apply. This is similar to the behavior of the van der Waals force.

Both the van der Waals force and the strong nuclear force are called “residual forces” in the literature. They are significantly weaker than the fundamental forces from which they derive: the electromagnetic force between nuclei and electrons and the strong interactions between quarks.

## Incompressibility

One characteristic of molecules in a liquid state is the familiar phenomenon of being incompressible, which means that a liquid's volume hardly decreases when pressure is applied to it. In fact, a liquid's specific volume<sup>24</sup> is almost constant, because when two molecules move toward one another, they first feel attraction due to the van der Waals force, but at a certain distance, a strong repulsive force appears. (This is due to the Pauli exclusion principle).<sup>25</sup>

A similar phenomenon is the density of nucleons inside the atomic nucleus. The nucleon density in a large nucleus is almost identical to that in a small nucleus (with the exception of very small nuclei).<sup>26</sup>

## Distance dependence of the potential

The curve in Figure 7 represents the distance dependence of the potential between two molecules.<sup>27</sup> The steep declining part of the curve on the left is attributed to the repulsive force that stems from the Pauli exclusion principle. The lowest point in this curve is the equilibrium state between the van der Waals attraction and the repulsive feature of the Pauli exclusion principle. The increase on the right is attributed to the van der Waals force that vanishes in distance (the curve touches the x-axis).

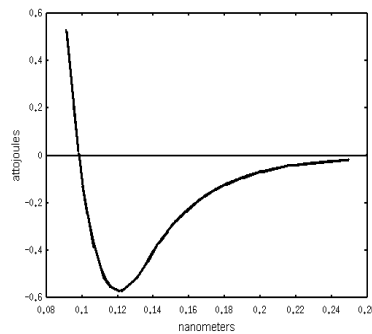


Figure 7. Potential – distance dependence of molecules

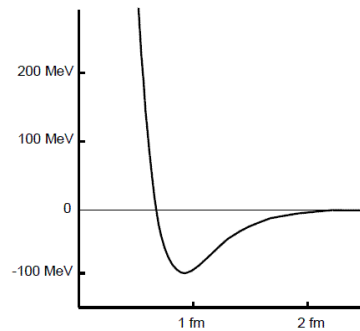


Figure 8. Potential – distance dependence of nucleons

The curve in Figure 8 describes the distance dependence of the strong nuclear force potential.<sup>28</sup> Needless to say, the two curves have very similar characteristics.

## The current theoretical status of the strong nuclear force

The similarity between the van der Waals force and the strong nuclear force has been known for at least 70 years. However, nuclear physicists maintain<sup>29</sup> that unlike the van der Waals force, the nuclear force cannot be derived from the current theory of strong interaction. Even QCD proponents admit that

<sup>24</sup> “Specific volume” is the volume per unit of mass.

<sup>25</sup> For an explanation of Pauli’s Exclusion Principle, look in the “Terminology” appendix.

<sup>26</sup> S. S. M. Wong, *Introductory Nuclear Physics*, (Wiley, New York 1998) p.139

<sup>27</sup> For a similar graph, see H. Haken and H. C. Wolf, *Molecular Physics and Elements of Quantum Chemistry*, (Springer, Berlin 1995). p.15

<sup>28</sup> For a similar graph, see S. S. M. Wong, *Introductory Nuclear Physics*, (Wiley, New York 1998). p.97

<sup>29</sup> S. S. M. Wong, *Introductory Nuclear Physics*, (Wiley, New York, 1998). p.102

the nuclear force seems to be incompatible with QCD<sup>30</sup>. A more detailed discussion of Wilczek's article appears later in this book in the chapter "And Yet, Why Do Scientists Believe in QCD?"

In fact, even today, the question of how the strong interaction explains the strong nuclear force is listed as one of the important unsolved problems in physics.<sup>31,32</sup>

### The volume of external electrons

The volume<sup>33</sup> of the external electrons of a molecule inside a droplet is larger than their volume in a free molecule<sup>34</sup>. This property is a consequence of the screening effect that allows electrons to penetrate into neighboring molecules. The electrons of liquid droplet molecules thus partially overlap each other.

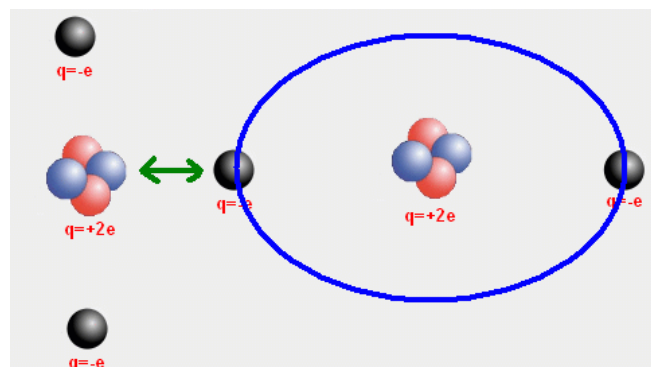


Figure 9. The larger volume of the electrons in liquid helium, caused by the attraction of electrons to the nuclei of neighboring atoms

A similar phenomenon was found in nucleons. In 1983, experiments discovered that the volume of nucleon quarks is larger for nucleons of a heavier nucleus<sup>35</sup>. This effect is called "the first EMC<sup>36</sup> effect" and it totally contradicted theoretical predictions published earlier.

The first EMC effect has been bewildering physicists up to the present day, since there is no consensus explanation accepted by the physics' community.<sup>37</sup>

<sup>30</sup> Frank Wilczek, *Hard-core revelations*, NATURE, Vol. **445** 156 (2007). "Ironically, from the perspective of QCD, the foundations of nuclear physics appear distinctly unsound".

<sup>31</sup> Wikipedia list of unsolved problems in physics (October 2010.)

<sup>32</sup> In Physical Review Letters, 2007, Ishii, Aoki and Hatsuda published an article that shows preliminary results in which lattice QCD explains the nuclear force. However, their calculations are very far from being considered as the final word. For example they use a pion's mass of 0.53 GeV whereas the true value is about 0.14 GeV. Other unphysical mass values are also used in their article.

<sup>33</sup> A simplified definition of the electron volume is the volume of the orbit of the electron around the molecule or atom.

<sup>34</sup> J. B. Pendry, *The electronic structure of liquids*, J. Phys. C, **13**, 3357 (1980)

<sup>35</sup> J.J. Aubert *et al.*, Phys. Lett. **123B**, 275 (1983). The graph on p. 277 shows that the  $x$  dependence of the structure function of iron is narrower than that of the deuteron. It follows that iron's quarks are enclosed in a larger spatial volume than that of the deuteron.

<sup>36</sup> European Muon Collaboration

<sup>37</sup> J. Arrington *et al.*, *New Measurements of the EMC Effect in Few-Body Nuclei*, J. Phys. Conference Series **69**, 012024 (2007). "So while the experimental signature is clear, the interpretation of this effect is, at present, ambiguous."

## Cross section curve

When a quite low energy beam hits an atom, it interacts with the electrons of the external shell. Then, according to quantum mechanical laws, as the beam's energy increases, the number of interaction events decreases. In such a case we say that “the cross section curve decreases.”

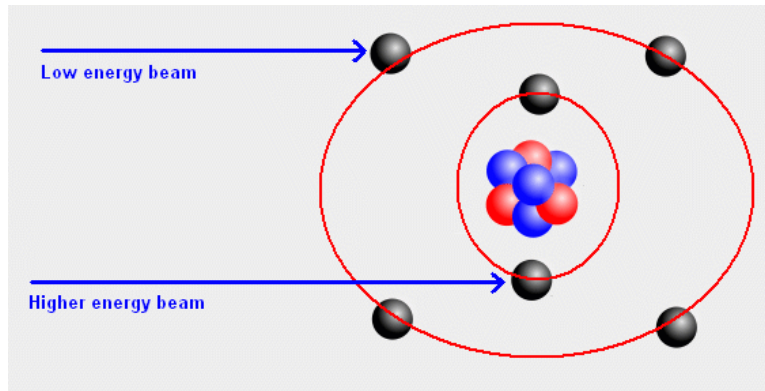


Figure 10. Interaction of a beam of electrons with the electrons in the atomic shells.

But when the energy of the beam is strong enough, then particles of the beam are able to excite the electrons belonging to the inner shells. Therefore, new participants enter the game, more hits are observed, and the cross section graph changes direction and begins to increase.<sup>38</sup>

This rise of the cross section curve as the beam energy increases and inner shells enter the process can also be observed in the shells of nucleons inside the atomic nucleus. It is well known that nucleons occupy shells inside the nucleus as electrons occupy shells in the atom. And indeed, when an electron beam hits a nucleus, a quite low energy electron beam can excite the nucleons in the external shell of the nucleus, and when the beam energy is sufficiently high it begins to excite inner shells as well.<sup>39</sup>

A similar cross section curve is observed inside the proton. In experiments conducted before 1997 the cross section graph of electron beams hitting the quarks within the protons went down as energy increased. But a 1994-1997 experiment at the DESY labs in Germany, with the highest electron-proton collision energy to date, the measured cross section was higher than expected. These findings were followed by the publication of papers expressing astonishment.<sup>40,41</sup> Scientists decided to conduct additional experiments in order to assure that these results were not just statistical fluctuations.

Experiments conducted during the early 2000s in the Tevatron collider at Fermi National Accelerator Laboratory, Illinois, reached sufficiently high beam energies and confirmed that the cross section graph of proton-proton (and proton-antiproton<sup>42</sup>) collisions stops decreasing and begins to increase.<sup>43</sup>

This phenomenon remains unexplained.<sup>44</sup>

<sup>38</sup> C. J. Powell, *Cross sections for ionization of inner-shell electrons by electrons*, Rev. Mod. Phys., **48**, 33 (1976).

<sup>39</sup> I. Sick *et al.*, *Charge density of <sup>40</sup>Ca*, Physics Letters B, Volume **88**, Issues 3-4, (1979). p.245-248

<sup>40</sup> C. Adloff *et al.*, *Observation of Events at Very High Q<sup>2</sup> in ep Collisions at HERA*, Z. Phys **C74**, 191 (1997).

<sup>41</sup> J. Breitweg *et al.*, *Comparison of ZEUS Data with Standard Model Predictions for ep -> eX Scattering at High x and Q<sup>2</sup>*, Z. Phys **C74**, 207 (1997).

<sup>42</sup> An explanation about particles and anti-particles will be provided in the chapter “Particle Classification”.

<sup>43</sup> K. Nakamura *et al.* (Particle Data Group), Journal of Physics **G37**, 075021 (2010). [pdg.lbl.gov/2010/reviews/rpp2010-rev-cross-section-plots.pdf](http://pdg.lbl.gov/2010/reviews/rpp2010-rev-cross-section-plots.pdf) (p. 12)

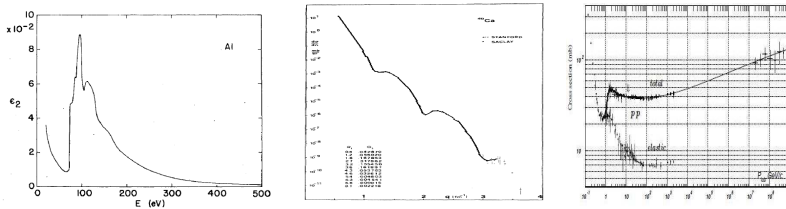


Figure 11. Regions of cross section curve rise in atoms (left), atomic nucleus (middle) and protons (right).

### Pairs of particle and antiparticle

In 1947, Lamb and Retherford conducted an experiment on hydrogen atoms and found a small shift of energies compared to predictions based on pure quantum mechanics, now known as “Lamb shift.” This result is well understood by a higher rank theory called quantum field theory. A simplified explanation of this shift is that the electronic state in the atom contains an additional pair of electron and anti-electron (called positron).<sup>45</sup>

The positron of the additional pair obeys the laws of electrodynamics and is evidently pushed from the atomic inner regions, because in these regions the nuclear field is only partially screened by electrons. Therefore, the positron, having a positive charge just like the atomic nucleus, should be located mostly in the atom’s periphery.

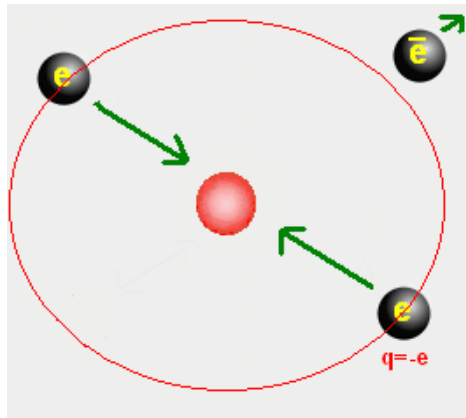


Figure 12. A state of the hydrogen atom containing an additional electron-positron pair. The positron is repelled by the atomic nucleus because both are positively charged

A similar phenomenon was found inside the proton. The proton has additional pairs of quark and antiquark beside the three valence quarks. Here antiquarks are measured explicitly and they tend to be in the proton’s peripheral region.<sup>46</sup>

<sup>44</sup> An attempt to explain this phenomenon was done by A. A. Arkhipov, [arxiv.org/PS\\_cache/hep-ph/pdf/9911/9911533v2.pdf](http://arxiv.org/PS_cache/hep-ph/pdf/9911/9911533v2.pdf). This author uses a kind of force which is inconsistent with the Standard Model.

<sup>45</sup> For every massive particle there is an “anti-particle” which has the same properties as the massive particle but opposite charge. The positron is the anti particle of the electron.

<sup>46</sup> D. H. Perkins, *Introduction to High Energy Physics*, (Addison-Wesley, Menlo Park, CA, 1987). p.281. The smaller x-width of the antiquarks graph and the uncertainty principle prove that the antiquarks’ volume is larger than that of quarks.

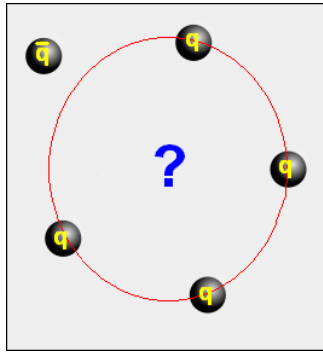


Figure 13. The antiquark is located in the peripheral region of the proton. This phenomenon is unexplained

## Proton form factor

In atoms there is probability to find the electron at a certain distance from the atomic center. It turns out that for the simple case of the ground state of the one electron hydrogen atom, the probability to find the electron close to the center is higher than the probability to find it at the periphery. This phenomenon is explained by quantum mechanics using the fact that the electromagnetic force that attracts the electron to the positively charged nucleus *decreases* while the distance between the electron and the nucleus *increases*. This issue is agreed by the entire physical community.

What is the probability to find the quarks at a certain distance from the nucleon center?

In the proton's case information on the spatial quark distribution is based on measurements. The analysis of the experimental data yields a mathematical quantity called "form factor." The form factor can be used for deriving the probability to find the quarks at different points inside the proton.

It was found that in the proton, similarly to the hydrogen atom, the probability to find the quarks near the proton center is higher.<sup>47</sup>

## The proton spin crisis

It is well known that the electrons in each atomic state exist in several configurations.<sup>48</sup> We will discuss this issue in detail later in this book. During the 1940s Wigner and Racah developed useful mathematical tools for calculating these configurations. As a result of these configurations, the sum of the electron spins<sup>49</sup> is much smaller than the total spin of a single configuration.<sup>50</sup>

A similar phenomenon occurs in the proton. In 1987 EMC measured the sum of the spins of quarks inside the proton, and found that the total was much smaller than the overall proton spin. This phenomenon is called the proton spin crisis and is considered one of the most important unsolved problems in physics.<sup>51</sup>

<sup>47</sup> D. H. Perkins, *Introduction to High Energy Physics* (Addison-Wesley, Menlo Park, CA, 1987). p. 194-196

<sup>48</sup> A.R.P. Rau, *Astronomy-inspired Atomic and Molecular Physics* (Kluwer Academic, Dordrecht, 2002). p. 16

<sup>49</sup> Spin is a fundamental characteristic property of particles. It is a kind of a quantum mechanical rotating top. The spin of a system of particles is the sum of spins of the individual particles, where the summation obeys quantum mechanical laws.

<sup>50</sup> The reason is that multiple configurations lead to cancellation of a major part of the contribution of the electrons' spin to the total angular momentum of the atom, because the spin is coupled to the spatial angular momentum and in different terms it takes opposite directions.

<sup>51</sup> Wikipedia list of unsolved problems in physics. [en.wikipedia.org/wiki/List\\_of\\_unsolved\\_problems\\_in\\_physics](http://en.wikipedia.org/wiki/List_of_unsolved_problems_in_physics)

## Baryon number conservation law

It is well known that the number of atoms is conserved in chemical interactions. This is because chemical processes involve the external electron shell of each atom, while the atomic nucleus remains unchanged. Therefore, the number of atoms does not change in chemical processes.

A similar phenomenon is found in baryons. Baryons are particles belonging to the proton and the neutron family. Different baryons have different setup of the three valence quarks. In all experiments to date, the number of baryons is conserved. This is inconsistent with theories that predict proton decay.<sup>52</sup>

## Tensor force between nucleons

According to the electromagnetic equations, when an electric charge moves in a loop, or when the charge has non-zero spin, it creates an axial magnetic dipole. The axial magnetic dipole is an axial magnet with two poles. When two axial magnetic dipoles are positioned near one another, they apply a force in a particular direction, which depends on the relative orientation of the axial magnetic dipoles and on the distance between them. This force is called “tensor force.” In most cases, the direction of the tensor force is not parallel to the line connecting the dipoles.

Some atoms, like the hydrogen atom, have non-zero spin and their electrons create axial magnetic dipoles. When two hydrogen atoms are positioned relatively far from one another,<sup>53</sup> then *in principle* a small tensor force is exerted by one atom on the other.

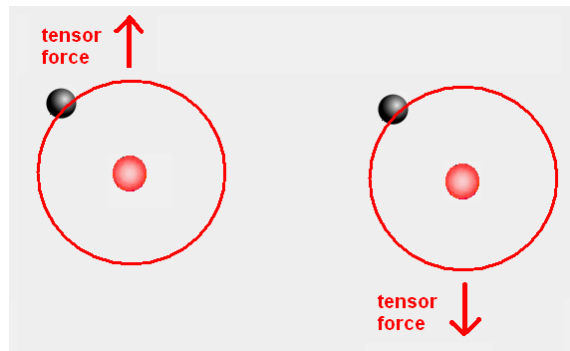


Figure 14. Atoms with spins generate magnetic dipoles and apply tensor forces on one another

The tensor force appears more effectively with nucleons. Protons and neutrons have non-zero spin, and they apply a tensor force on one another. As far as we know, the question as to what causes the tensor force is still open.

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<sup>52</sup> Howard Georgi and Sheldon Glashow, *Unity of All Elementary-Particle Forces*, Physical Review Letters, **32** 438 (1974).

<sup>53</sup> When two hydrogen atoms come close to each other they create hydrogen molecule (H<sub>2</sub>) and destroy the magnetic axial dipoles of the combined system.

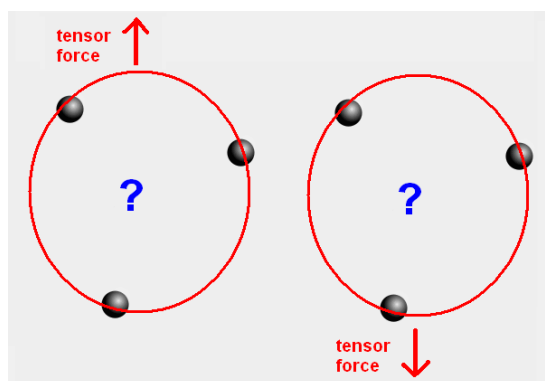


Figure 15. Nucleons apply tensor force one on another.

## Strong CP problem

Electromagnetic force, operating between electrons and protons, obeys the law of C (charge conjugation) and P (Parity) conservation. This means that in a world in which matter becomes anti-matter, or in a mirror world, where right and left are interchanged, the same electromagnetic laws apply.

The same applies to strong interaction: experimental findings indicate that the strong interaction is invariant under charge conjugation and under parity transformations.

However, the current theory of particle physics, the standard model, predicts that strong interaction should violate CP. In the literature, this problem is called the “strong CP problem,” and is considered one of the most important unsolved problems in physics.<sup>54</sup>

## Interaction with light

According to electromagnetic theory, when a beam of light hits an atom, it interacts only with electric charges. And indeed, light interacts with the electrons of the atom, and energy may be transferred from the photon to the electron. This effect is called the “photoelectric effect”.

About 50 years ago, physicists discovered that energetic photons interact with the quarks more intensely than expected by the quarks’ electric charge. Moreover, the interaction of energetic photons with both protons and neutrons is very similar, although the protons are electrically charged, and the neutrons are not. Physicists agree that this cannot be explained by the quarks’ electric charge. A theory explaining this phenomenon was published in the 1960s,<sup>55</sup> but was later removed from most of the textbooks and is not considered as a valid theory. As of today, there is no other accepted explanation of this fundamental phenomenon.

## Let’s compare

### Table 1. A comparison between electromagnetic force and strong interaction.

<sup>54</sup> Wikipedia list of unsolved problems in physics. [en.wikipedia.org/wiki/List\\_of\\_unsolved\\_problems\\_in\\_physics](https://en.wikipedia.org/wiki/List_of_unsolved_problems_in_physics) (November 2010)

<sup>55</sup> T. H. Bauer, R. D. Spital, D. R. Yennie and F. M. Pipkin, *The hadronic properties of the photon in high-energy interactions*, Rev. Mod. Phys., **50**, 261-436 (1978).

	<b>Electromagnetic force and electrons</b>	<b>Strong interaction and quarks</b>
1	Holds electrons inside an atom or a molecule by means of a relatively strong force.	Holds quarks inside a nucleon by means of a strong force.
2	Holds molecules within a liquid droplet by means of a much weaker force (the van der Waals force).	Holds nucleons inside a nucleus by means of a much weaker force (the strong nuclear force).
3	Cancels rapidly when the molecules are far apart from each other.	Cancels rapidly when the nucleons are far apart from each other.
4	Liquid molecules have a quasi-constant density.	Nucleons within atomic nucleus have a quasi-constant density.*
5	The volume of electrons of a molecule inside a liquid droplet is larger than that of a free molecule.	The volume of nucleonic quarks inside a heavy atomic nucleus is larger than that of the deuteron (first EMC effect).*
6	The graph describing distance dependence of the molecular force potential looks like a Ski Jump curve.	The graph describing distance dependence of the nuclear force potential looks like a Ski Jump curve.*
7	If the collision energy is high enough, the cross section graph increases.	If the collision energy is high enough, the cross section graph increases.*
8	Due to quantum field theory, atoms contain a very small amount of additional pairs of electron and positron.	Nucleons contain additional pairs of quark and antiquark.

9	According to electrodynamics the positron of this pair tends to be located away from the center of the atom.	Experiments show that antiquarks tend to be located away from the center of nucleon.*
10	The electrons tend to be close to the atomic center.	The quarks tend to be close to the proton center.*
11	Electron spins do not accumulate.	Quarks spins do not accumulate (proton spin crisis).*
12	The number of atoms doesn't change in chemical interaction.	The number of baryons doesn't change in any interaction.*
13	In principle, two spatially distant atoms with non-zero spin apply a tensor force on one another.	Nucleons have non-zero spin and two nucleons apply a tensor force on one another.*
14	The electromagnetic force does not violate CP.	The strong interactions do not violate CP (strong CP problem).*
15	Photons interact with electrons.	Photons interact strongly with quarks.*

\* Unexplained experimental result

It turns out that the characteristics of molecules/atoms are amazingly similar to those of nucleons, if we substitute an atomic nucleus for a droplet of molecules, nucleons for molecules/atoms, and quarks for electrons. Most of these experimental results have remained unexplained, possibly because they are incompatible with QCD, the currently admitted theory.

Is nature trying to tell us something?

Can you, the reader, deduce the structure of the nucleons?

Can you deduce the kind of forces which hold quarks inside nucleons?

## **Chapter 2: Non-Conservation of Knowledge**

One of the consequences of the outstanding development of scientific knowledge in modern times, and its extensive ramifications, is that no scientist could possibly be familiar with all the scientific facts, discoveries and information, not even within his or her own field of specialization.

The strength of a scientific community lies in its capacity to preserve acquired, validated knowledge and develop it further. It is therefore quite hard to understand how, when physicists discover the extent to which QCD fails to explain a large number of experimental findings, their common reaction is surprise, which then turns into disbelief, suspicion and sometimes even aggressiveness.

Most physicists are well aware of the fact that QCD is unable to explain the strong nuclear force. The strong nuclear force and other phenomena, such as the “proton spin crisis” and the “strong CP problem,” are famous “waiting to be solved” problems.

Many other problems – some of which will be presented in this book – actually contradict QCD, but for some reason, have never been properly addressed.

### **Interaction of photons with nucleons**

The interaction of electromagnetic waves with electric charges has been considered as a milestone in physics since the 19<sup>th</sup> century with the introduction of Maxwell’s equations. Countless devices we use in our daily life are based on this phenomenon. The development of quantum mechanics at the beginning of the previous century and the discovery of the photoelectric effect extended this knowledge to the photon.<sup>56</sup>

Some fifty years ago, scientists were amazed to discover that energetic photons were reacting to the forces inside the nucleons as well.<sup>57,58</sup>

From a theoretical perspective, the significance of this phenomenon is just as important as the interaction of photons with electric charges. In fact, the interaction of photons with strongly interacting particles (called quarks) seems to provide an important clue for the existence of a common denominator between electromagnetic and strong interactions. The above mentioned long list of

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<sup>56</sup> In 1905, Albert Einstein explained the photoelectric effect by describing light as composed of discrete quanta, now called photons.

<sup>57</sup> T. H. Bauer, R. D. Spital, D. R. Yennie and F. M. Pipkin, *The hadronic properties of the photon in high-energy interactions*, Rev. Mod. Phys., **50**, 261-436 (1978).

<sup>58</sup> This photon related force is much stronger than its well known interaction with the charge constituents of the nucleons. Moreover, although the proton and the neutron have different electric charge, they interact about the same with energetic photons.

similarities between electromagnetic systems of electrons and strongly interacting systems of quarks, “cries out” for finding such a common denominator.

The newly discovered phenomenon was very fashionable during the 1960s, starring in graduate physics study programs and attracting scientists’ comprehensive efforts to explain it. But as the years passed, and no theory seemed to be capable of providing a satisfactory explanation, the phenomenon fell into oblivion. A review of four<sup>59,60,61,62</sup> of the particle physics textbooks currently used in graduate schools, shows that this issue is not even mentioned.

Furthermore, in Wikipedia, the most comprehensive encyclopedia existing today, this phenomenon doesn’t appear in the Photon topic. In fact, it appears in Wikipedia only once, in a short, vague comment.<sup>63</sup>

It turns out that such a fundamental phenomenon, of the same significance as the photoelectric effect itself, receives only negligible attention. It is nothing less than a disgrace that most physicists are not even aware of this property of the photon.

### The first EMC effect

A paper published in January 1983<sup>64</sup> reported experimental findings according to which the volume of nucleon’s quarks in heavy nuclei is larger than their volume inside the deuteron. The authors indicated that this phenomenon contradicted all theoretical predictions.

Since then, no scientific theory explaining this result has been introduced.<sup>65</sup> This intriguing phenomenon is not even mentioned in graduate study programs and most physicists would hardly be capable of understanding its nature even after searching the literature.

As far as we know, the only reference to the phenomenon in Wikipedia is one vague comment.<sup>66</sup>

### The proton-proton cross-section curve

Two papers published in 1997<sup>67,68</sup> reported an unexplained increase in the number of events for very high energy electrons/positrons scattering on protons, compared to the expected value. Nearly every

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<sup>59</sup> D.H. Perkins, *Introduction to high energy physics*, (4<sup>th</sup> ed. Cambridge University Press, 2000).

<sup>60</sup> D.J. Griffiths, *Introduction to elementary particles*, (2<sup>nd</sup>, rev. ed. Weinheim : Wiley-VCH, 2008)

<sup>61</sup> F. Halzen and A.D. Martin *Quarks and leptons*, (New York : Wiley, 1984)

<sup>62</sup> Fayyazuddin and Riazuddin, *A modern introduction to particle physics*, (2<sup>nd</sup> ed. Singapore : World Scientific, 2000)

<sup>63</sup> en.wikipedia.org/wiki/Vector\_meson\_dominance. *In physics, vector meson dominance was a model developed by J. J. Sakurai in the 1960s before the advent of QCD in order to describe interactions between photons and hadronic matter. In particular the hadronic components of the photon polarization tensor consist of the lightest vector mesons  $\rho$ ,  $\omega$  and  $\phi$ . Therefore interactions between photons and hadronic matter occur by the exchange of a hadron between the dressed photon and the hadronic target.*

<sup>64</sup> J.J. Aubert *et al.*, Phys. Lett. **123B**, 275 (1983).

<sup>65</sup> J. Arrington *et al.*, J. Phys. Conference Series, **69**, 012024 (2007).

<sup>66</sup> en.wikipedia.org/wiki/European\_Muon\_Collaboration. *In 1983, EMC discovered that nucleons inside a nucleus have a different distribution of momentum among their component quarks. This is the original so-called “EMC Effect”.*

<sup>67</sup> C. Adloff *et al.*, *Observation of Events at Very High Q<sup>2</sup> in ep Collisions at HERA*, Z. Phys **C74**, 191 (1997)

physicist would agree that the only plausible explanation for this finding is the existence of additional massive objects inside the proton, which contradicts the consensus theory.<sup>69</sup> This experimental data was regarded as inconclusive because of the small number of events.

An analogous experimental finding has been verified beyond any doubt in an experiment at the Tevatron particle collider in the beginning of the 2000s. This machine measures proton-proton and proton-antiproton collisions at very high energy. The results clearly show that for high energy both the elastic and the total cross-section curves stop decreasing and begin to increase.<sup>70</sup>

There are hardly any papers dealing with this fundamental issue, although the consequences of this result would totally shake the common belief about the structure of nucleons. A search in Wikipedia shows no mention of this finding, either.

Claims stating that the increase of the proton-proton cross section curve is inconsistent with QCD have already been published a decade ago<sup>71</sup>. No adequate discussion of this problem can be found in the scientific literature.

It turns out that a perfectly valid experimental finding, which seems to contradict the dominant theory, is universally ignored.

## The NIH syndrome

The NIH (Not Invented Here) syndrome is a term used to describe a culture that avoids using knowledge because of its external origins. This term was coined to describe the attitude of large high tech companies in the past, but it can unfortunately characterize many particle physicists who ignore physical theories attributed to neighboring research fields. Established physical evidence other than that conceived by particle physicists is often totally ignored, and sometimes even overtly scorned.

For example, historically, QCD color force was invented in order to solve the puzzle of the  $\Delta^{++}$ ,  $\Delta^-$  and  $\Omega^-$  particles. During the 1960s, particle physicists thought that these particle properties contradicted the Pauli exclusion principle, which is considered to be a fundamental concept in quantum mechanics.<sup>72</sup> A simplified formulation of Pauli's principle states that two identical fermions<sup>73</sup> cannot exist in the same quantum state. In  $\Delta^{++}$ ,  $\Delta^-$  and  $\Omega^-$  there are three identical fermions in the external shell (three  $u$  quarks in the case of  $\Delta^{++}$ , three  $d$  quarks in  $\Delta^-$  and three  $s$  quarks in  $\Omega^-$ ). The total spin and parity of each of these particles is  $3/2^{+74}$  and the total isospin of the  $\Delta$  baryons is  $3/2$ .

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<sup>68</sup> J. Breitweg *et al.*, *Comparison of ZEUS Data with Standard Model Predictions for  $ep \rightarrow eX$  Scattering at High  $x$  and  $Q^2$* , *Z. Phys* **C74**, 207 (1997)

<sup>69</sup> "If the results are not a statistical fluke, new physics has been observed. One possibility is that our understanding of what's inside the proton is somehow wrong". Frank Sciulli, Columbia University News, 1997.

<sup>70</sup> C. Amsler *et al.* (Particle Data Group) *Physics Letters* **B667**, 1 (2008). p.12. [pdg.lbl.gov/2009/reviews/rpp2009-rev-cross-section-plots.pdf](http://pdg.lbl.gov/2009/reviews/rpp2009-rev-cross-section-plots.pdf)

<sup>71</sup> A. A. Arkhipov, [arxiv.org/PS\\_cache/hep-ph/pdf/9911/9911533v2.pdf](http://arxiv.org/PS_cache/hep-ph/pdf/9911/9911533v2.pdf).

<sup>72</sup> F. Halzen and A. D. Martin, *Quarks and Leptons* (Wiley, New York, 1984). p.5

<sup>73</sup> Electrons, nucleons and quarks are examples of fermions

<sup>74</sup> Parity is an important property of a quantum state. Its standard notation is a superscript + (-) for a positive (negative) parity. See the "Terminology" appendix.

Particle physicists considered this relatively stable combination impossible without the invention of QCD colors.

However, such combinations do exist in nature, and this is well known to nuclear physicists.

It is well known that the atomic nucleus contains nucleons, and they reside in shells.<sup>75</sup> Let's examine several nuclei that have 31 nucleons: silicon  $^{31}\text{Si}$ , phosphorus  $^{31}\text{P}$ , sulfur  $^{31}\text{S}$ , and chlorine  $^{31}\text{Cl}$ . All of them have 14 protons and 14 neutrons in their internal closed shells, and 3 nucleons in their nucleus' external shells. Silicon has three neutrons, phosphorus has two neutrons and one proton, sulfur has two protons and one neutron and chlorine has three protons in its nucleus external shells.

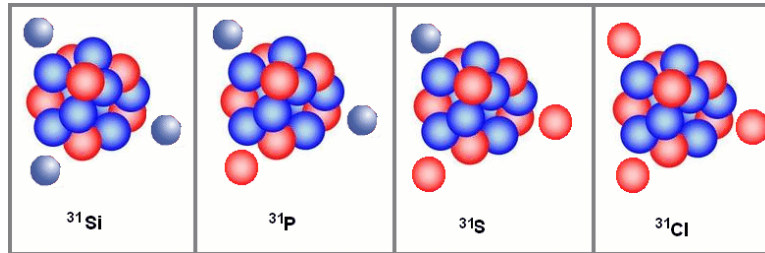


Figure 16. The structure of the nuclei of silicon, phosphorus, sulfur and chlorine that contain 31 nucleons

Quantum states of these isotopes demonstrate an analogy to the baryons  $\Delta^-$  (with  $ddd$  quarks), neutron and  $\Delta^0$  ( $udd$ ), proton and  $\Delta^+$  ( $uud$ ) and  $\Delta^{++}$  ( $uuu$ ). Here too, nucleons are fermions that obey the Pauli exclusion principle and a spin, parity and isospin correspondence exists between the nuclear and the quark states.

If we follow the “proof” that particle physicists provided that  $\Delta^{++}$  and  $\Omega^-$  cannot exist without colors then we will see that the same “proof” holds for the ground state of the nuclei  $^{31}\text{Si}$  and  $^{31}\text{Cl}$ .

Why then is there a rather stable  $^{31}\text{Si}$  isotope with three neutrons in its external shell? And why does the isotope  $^{31}\text{Cl}$  with three such protons exist?<sup>76</sup> Both isotopes have spin-parity  $3/2^+$  and isospin  $3/2$  like  $\Delta^-$  and  $\Delta^{++}$ . If such particles exist in nature without colors, then why is the invention of colors needed to explain  $\Delta^{++}$ ,  $\Delta^-$  or  $\Omega^-$ ?<sup>77</sup>

## The disregarded theory

It is well known that electrons in the atom are structured in shells. The first shell is called “1S” and it may contain two electrons at most. Too many textbooks claim that in the helium atom “ground state”<sup>78</sup> the two electrons reside only in the “1s” shell.<sup>79,80</sup> This is taught as a scientific truth and provided in countless academic web sites.<sup>81,82,83</sup>

<sup>75</sup> M.G. Mayer, *On closed shells in nuclei*, Phys. Rev. **74** (1948). p.235-239

<sup>76</sup> These isotopes disintegrate because of weak interactions.

<sup>77</sup> E. Comay, *On the Quantum Mechanical State of the  $\Delta^{++}$  baryon*, Prog. in Phys. **1**, 75 (2011). [tau.ac.il/~elicomay/dpp\\_fin.pdf](http://tau.ac.il/~elicomay/dpp_fin.pdf)

<sup>78</sup> Ground state of an atom is its lowest energy state

<sup>79</sup> John Olmsted, Gregory M. Williams, *Chemistry, the molecular science*, (John Wiley & Sons, Inc), p. 310

<sup>80</sup> Frank H. Shu, *The physical universe: an introduction to astronomy*, p.51

<sup>81</sup> [hyperphysics.phy-astr.gsu.edu/hbase/quantum/helium.html](http://hyperphysics.phy-astr.gsu.edu/hbase/quantum/helium.html)

<sup>82</sup> [wiki.brown.edu/confluence/download/attachments/29133/Helium+and+Calcium.pdf](http://wiki.brown.edu/confluence/download/attachments/29133/Helium+and+Calcium.pdf)

This is simply wrong. It was very well known that the electron shells in the atom are far more complicated than is generally admitted. Calculations based on a well-established mathematical theory developed by Wigner and Racah during the 1940s have proven this. Physicists knew 60 years ago that electrons are stored in several configurations simultaneously.<sup>84</sup>

Physicists may argue that the claim that the electrons are in one shell is a legitimate approximation of reality. However, this is not so. First of all, the helium configurations were calculated and it appears that even in this simple two-electron atom, there is quite a high probability that the electrons are stored in several configurations.<sup>85</sup>

But more important, for our discussion, is that physicists use the same wrong arguments to explain the physical properties of quarks. Furthermore, it seems that they do not take into account the profound reasons that multiple configurations reduce energy level. As we will see in this book, if they would adopt the well-established configuration concept, they would be amazed to discover that it offers a solution to one of the major problems of the last few decades: the proton spin crisis. Furthermore, it provides better understanding of the structure of baryons and the properties of  $\Delta^{++}$  and  $\Omega^-$  baryons.

Sixty years ago, after physicists found that nucleons occupy shells in the nucleus, Racah extended the applications of his mathematical theory in order to calculate the states of nucleons in the atomic nucleus.<sup>86</sup> It is reasonable to believe that Racah would have tried to extend his theory further in order to explain the quark properties after they were discovered during the 1960s. Unfortunately, Racah passed away in 1965 and no one made any further efforts in this direction.

Today, publishing articles in this field in mainstream physics journals is nearly impossible. In fact, as an important scientific editor candidly said, such articles could not be published because they could not go through the mandatory procedure of peer review; no scientist he knew of would be capable of reviewing such papers.

## The search for new particles

Four years after Dirac published a paper that was used for predicting the existence of the positron, the particle was discovered. The non-discovery of the positron would have most likely resulted in the collapse of Dirac's theory, which predicted the existence of anti-matter.

In 1961 Gell-Mann and Ne'eman used the mathematical model of the SU(3) symmetry group to predict the existence of the  $\Omega^-$  particle. The particle was discovered three years later. The non-discovery of this particle would have disqualified Gell-Mann and Ne'eman's entire theory, which constitutes the foundation for the quarks.

On the other hand, QCD predicts the existence of many types of particles and matter, such as dibaryons, glueballs, pentaquarks and strange quark matter. Several decades have elapsed since the

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<sup>83</sup> [quantummechanics.ucsd.edu/ph130a/130\\_notes/node35.html](http://quantummechanics.ucsd.edu/ph130a/130_notes/node35.html)

<sup>84</sup> G.R. Taylor and R.G. Parr, *Superposition of configurations: The helium atom*, Proc., Natl.Acad. Sci. USA **38**, (1952). p.154-160

<sup>85</sup> AW Weiss, *Configuration Interaction in Simple Atomic Systems*, Phys. Rev. **122**, (1961). p.1826–1836

<sup>86</sup> G. Racah, *Directional correlations of successive nuclear radiations*, Phys. Rev. **84** (1951). p.910-912

theoretical predictions of these objects and yet, despite huge investments of experimental efforts, the existence of none of these entities has ever been confirmed.

But for some reason, although these particles have not been discovered, the theory used for predicting them has not been questioned. Within a few decades, after the experimental search stops, the unsuccessful predictions will probably be forgotten.

### **Chapter 3: The Scope of this Book**

The 20<sup>th</sup> century witnessed the development of a branch of physics called quantum mechanics, resulting in major technological breakthroughs. In the 1950s and 1960s, physicists were aware of the existence of two particles considered impossible according to quantum mechanics. These particles were the  $\Delta^{++}$  and the  $\Omega^-$ .

During the 1960s it was already known that protons and many other particles are composed of smaller entities, the quarks. The particles  $\Omega^-$  and  $\Delta^{++}$  were known to be composed of quarks as well, but as discussed earlier in this book, the quark combinations and their properties did not seem coherent. At that time, it was not known that the quarks carry only half of the proton mass, and physicists thought that the quarks were the only *massive* objects inside the proton. Even today QCD supporters agree to the claim that quarks are the only kind of massive constituents of the proton.

The discovery of  $\Omega^-$  and  $\Delta^{++}$  seriously challenged the knowledge acquired up until then, seriously enough to motivate scientists to concentrate their efforts on the development of a new physical theory, based on a series of fantastic assumptions, describing forces and particles unlike anything known up to that point in time. The theory, called QCD, a central pillar of the standard model, won unshakable status as far back as the 1970s, in spite of a long series of incompatibilities with experimental findings (described in detail later on in this book).

Eliyahu Comay was a physics student during the 1960s at the Hebrew University of Jerusalem, where the eminent physicist Yoel Racah, was a revered figure. The physics program at the Hebrew University was particularly focused on the theory Racah developed in parallel with Wigner. Comay recognized, in the early 1970s, that  $\Omega^-$  and  $\Delta^{++}$  can be naturally explained by the theory developed by Wigner and Racah, in combination with the basic laws of quantum mechanics. Comay also realized that the masses of particles composed of quarks were consistent with the laws of quantum theory, established long before the invention of QCD.

Comay further specialized in nuclear physics. This was how he discovered that QCD's description of the forces inside the atomic nucleus was incorrect.

In 1983, Comay made an astonishing discovery, critical for understanding the physical properties of quarks, and the fundamental role of photons in strong interaction. This discovery allowed him to formalize the equations of quarks and to develop an alternative model, explaining familiar phenomena in an amazingly simple way, including phenomena which cannot be explained by QCD.

## The scope of Comay's model

The experimental findings below are explained in Comay's model. These results do not have accepted explanation, and they seem to contradict QCD (all the terms below will be explained later in this book):

- Protons and neutrons behave similarly when a hard photon hits them.
- Protons and neutrons interact strongly when a hard photon hits them.
- The first EMC effect.
- The proton spin crisis.
- The strong CP problem.
- The potential vs. distance graph of van-der-Waals and strong nuclear forces are similar.
- Nucleons within the atomic nucleus have a practically uniform density.
- The nuclear tensor force and its sign.
- Antiquarks have a larger volume inside nucleons.
- The neutron's negative electric charge tends to be found in external regions.
- Slow decrease of the proton-proton cross section in an appropriate high energy region.
- Increase in very high energy proton-proton elastic cross section.
- Proton form factor.
- Pentaquarks were not found.
- Strange quark matter was not found.
- Glueballs were not found.
- Dibaryons were not found.

Comay's model explains other findings that do not contradict QCD, although some of them don't have an explanation yet:

- Linear momentum of quarks accounts for only half of proton momentum.
- Quark confinement.
- The properties of the  $\Omega^-$  and the  $\Delta^{++}$  baryons.
- The three jet event.
- Meson radius relations.
- The relation between the proton's radius and the pion's radius.
- Problems with mass differences between mesons and baryons.
- The strong force ceases to act at a certain distance (cutoff).

- $\pi^0$  decay.
- Mesons are not confined inside the nucleon.
- Baryon number conservation law.
- Proton decay was not observed.
- The quarks  $u, d$  are heavier in baryons rather than mesons, and quarks having other flavors are heavier in mesons rather than baryons.
- Genuine Yukawa particle and the Higgs particle were not discovered. In fact, Comay shows that there is no elementary point-like spinless particle.
- Dirac monopoles were not discovered.

Most of Comay's work was conducted and published during 1980s and 1990s. A concluding article that summarizes most of his findings regarding his model was published in 2004.<sup>87</sup>

Using everyday language, this book will cover many topics, some highly advanced, in quantum mechanics, quantum field theory, Wigner and Racah calculus and their tremendous impact on the strong force, and more. This will allow us to understand the solution to more than a dozen unsolved problems listed above, some of which feature in the list of the most important unsolved problems in physics.

Further, we will try to explain the historical events that brought the particle physics to its current bizarre situation.

## Clarifications

Apart from special and general relativity, quantum mechanics is one of the most important development in 20<sup>th</sup>-century physics. During the 1940s and 1950s the development of quantum field theory allowed physicists to predict phenomena with outstanding accuracy, to a much larger extent than ever before. However, since the emergence of QCD in the 1970s, it would be fair to say that the branch of particle physics is in trouble.

The entire standard model is not challenged here. It would be reasonable to assume that many parts of the model, unrelated to QCD, could be valid, for example the notion of three generations of elementary particles or the Drell-Yan process, which Comay considers good to be and real achievements in physics. Comay further considers the works of Gell-Mann and Ne'eman and of Feynman and Bjorken to be some of the best bodies of work done in decades. Gell-Mann and Ne'eman provided convincing arguments for the existence of quarks as elements accounting for the structure of hadrons, and Feynman's and Bjorken's works established the theoretical basis for the dynamical properties of quarks which have been proven later in experiments.

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<sup>87</sup> *A Regular Monopole Theory and its Application to Strong Interactions*, Published in "Has the Last Word been Said on Classical Electrodynamics?" (Rinton Press, NJ, 2004). [tau.ac.il/~elicomay/LastWord.pdf](http://tau.ac.il/~elicomay/LastWord.pdf)

These theoretical works and the experiments related to them validate quarks' existence. Historically they preceded QCD and are independent of it. Therefore, the assumption that quarks constitute a central element in every theory of the strong interaction seems valid beyond any doubt.

The weak force, which is described in detail in the standard model, will not at all be discussed in this book. We believe that most of the issues regarding the strong interaction can be apprehended without getting into the complexities of the weak force.

### **The structure of this book**

The target readership of this book is mixed. It is targeted to any person who has a good understanding on physics, physics students, and even particle physics experts. The latter may use this book as an easy to read introduction to the corresponding scientific articles.

All the chapters in this book contain new and innovative perspective on issues in particle physics related to the strong interaction, except for the chapter "particle classification," which contains only basic material. Most of the chapters start with some background and continue with deeper discussion.

The next unit of the book, "The shell model of the proton," shows the advantage of explaining strong interaction as a force with similarities to the electromagnetic force.

The third unit, "Additional mass in the proton," discusses phenomena proving that the nucleons must contain massive objects in addition to the three valence quarks and the associated quark-antiquark pairs, and provides some calculations of mass and radius properties of baryons and mesons. The calculations may be a bit difficult for some readers. Readers may skip the sections discussing these calculations.

The fourth unit, "Magnetic monopoles," discusses the theory that Comay developed in the 1980s regarding the physical properties of quarks. This theory constitutes the foundation of the entire model.

The fifth unit, "Summary," starts with an important chapter called "And Yet, Why Do Scientists Believe in QCD?" In this chapter we present the arguments that were provided by particle physics experts in order to convince us that QCD must be correct. These arguments were collected from meetings we had with leading scientists in the field and correspondence with other experts. The last chapters in this part summarize the current situation.

The "Terminology" appendix contains definitions of basic terms for the benefit of people who are not particle physicists. The "Selected Articles of Eliyahu Comay" appendix contains abstracts of some of the relevant articles published during the last 30 years.