

# Constituent Quarks of the First Generation

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For our analysis, we introduce a virtual particle, which we call the fundamental particle [1], whose mass  $m_f$  and radius are given by:

$$m_f = 1.0886217 * 10^{-28} \text{ kg}, \quad r_f = 3.231309 * 10^{-15} \text{ m}, \quad (1)$$

These values satisfy the condition derived from the well-known form of the  $\hbar/c$  relation, which follows from the standard definition of the reduced Compton wavelength (2):

$$\lambda = \hbar / (c * m) \quad (2)$$

valid for elementary particles, including the proton [2]. Using the expressions from [3], we obtain:

$$r_f = (2\pi)^{1/3} * 2^{cy/9} * (m_{pl}/m_p)^{-8/9} * \lambda_p = 3.231308824E-15 \quad (3)$$

$$m_f = (2\pi)^{-1/3} * 2^{-cy/9} * (m_{pl}/m_p)^{8/9} * m_p = 1.088621711E-28 \quad (4)$$

Here:

- $m_{pl}$  – denotes the Planck mass,
- $l_{pl}$  – the Planck length,
- $m_p$  – the proton mass,
- $\lambda_p$  – the reduced Compton wavelength of the proton.

By multiplying expressions (3) and (4), the first three factors cancel, yielding:

$$r_f * m_f = \lambda_p * m_p = \hbar/c \quad (5)$$

The fundamental particle is unique in that, although it possesses well-defined mass and radius, it in fact represents a virtual limiting value—a theoretical reference point analogous to the Planck mass and/or the Planck length, which define the boundaries of physical processes. For this reason, when referring to the fundamental particle, we will also use the term fundamental limit.

This corresponds to a structural quantum state surrounding a virtual fundamental particle, an idea that has been indicated—each in their own way—by several researchers. Among them, we highlight two: Steven Weinberg in [4, p. 619, equation (11.4.2)] and Stevan Bošnjak, whose understanding was closest to this concept and who states [5, p. 219]:

$$\hbar/c = 2.202 * 10^{-37} \text{ cm} \cdot \text{g}, \quad m \cdot \lambda = 2.202 * 10^{-37} \text{ cm} \cdot \text{g}.$$

Let us define the *non-cohesion* limit of an elementary particle as:

$$r = r_f * (m/m_f)^{0.5} \quad (6)$$

Here, the state in the vicinity of the fundamental limit will be represented solely through the final dimensionless formula (7) for the mass increment relative to the previous one (index  $n-1$ ) [1].

$$m_n = m_{n-1} * \left( 1 + \frac{\hbar / c}{r_{n-1} * m_{n-1}} \right) = m_{n-1} * \left( 1 + \frac{r_f * m_f}{r_{n-1} * m_{n-1}} \right) \quad (7)$$

By substituting (5) and (6) into (7), we obtain:

$$m_n = m_{n-1} * \left( 1 + \frac{m_f^{1.5}}{m_{n-1}^{1.5}} \right) = m_{n-1} + \sqrt{\frac{m_f^3}{m_{n-1}}} \quad (8)$$

If we define the dimensionless quantity  $x$  by reducing the mass with respect to  $m_f$ ,

$$x = m / m_f \quad (9a)$$

we obtain:

$$x_n = x_{n-1} + x_{n-1}^{-0.5} \quad (9b)$$

which is a dimensionless formula for the mass increment. At each step, a portion of the content smaller than  $\hbar/c$  that lies within the *non-cohesion* boundary is captured. Since for *up* and *down* quarks  $m < m_f$ , they are therefore the only ones that can exist in a bound state, i.e., in mesons, protons, and neutrons, as so-called constituent quarks.

In this way, the constituent quark “emerges” through a mass increment expressed by the ratio of Planck’s constant ( $\hbar$ ) to the speed of light ( $c$ ),  $\hbar/c$ , which introduces reduced quantities that link mass and length independently of the choice of units.

The use of dimensionless reduced quantities significantly simplifies the treatment of elementary particles and enables a clearer analysis of their mutual relationships.

This is not a case of converting energy into mass (according to  $E=mc^2$ ), but rather of a **structural quantum state** that forms around a virtual fundamental limit.

If the reduced Compton wavelength (2) is expressed relative to  $r_f$  and denoted by  $r_c$ , we obtain:

$$r_c = \lambda / r_f = (\hbar/cm)/r_f = (m_f * r_f / m) / r_f = m_f / m = 1/x \quad (10)$$

Which we consider to represent Bošković’s *cohesion* limit of elementary particle [6]:

Formula (9b) is applied repeatedly to the reduced masses (Table 1),  $x = m/m_f$ . Its successive application yields the masses of mesons, then of the proton, and in the third step of the neutron,

with *up* and *down* quarks modeled via non-cohesive boundaries. In doing so, it is observed that lighter quarks acquire a larger mass increment than heavier ones, which is a well-known fact.

In the domain of masses and radii smaller than that of the fundamental particle, we identify two “bare” first-generation quarks—*up* and *down*—obtained by heuristic means.

$$m_u = 8.37317614 \cdot 10^{-30} \text{ kg}, \quad m_d = 8.37317614 \cdot 10^{-30} \text{ kg} \quad (11)$$

**Table – Quantum mass increment of quarks from (11) via formula (9b)**

	$x_0 = m/m_f$	$x_1 = x_0 + x_0^{-0.5}$	$x_2 = x_1 + x_1^{-0.5}$	$x_3 = x_2 + x_2^{-0.5}$
<i>d</i>	0.07691539	3.68264687277	4.20374553917	4.69147814535
<i>u</i>	0.03844904	5.13829736663	5.57945153059	6.00280609395
$m_{pr} = m_f \cdot (2u_2 + d_2) =$			1.67241128117E-27	2.10642520635E-31
$m_{ne} = m_f \cdot (u_3 + 2 \cdot d_3) =$				1.67492749791E-27

We have used the masses of bare quarks (with the note that other, and even imaginary, solutions are also possible). The second iteration yields the mass of the proton, understood as a system composed of two *up* quarks and one *down* quark, with a remaining mass of  $m_{gl} = 2.106425206 \cdot 10^{-31} \text{ kg}$ , which may be attributed to the contribution of gluons.

The third step yields the mass of the neutron (13), which consists of two *down* quarks and one *up* quark. In expressions (12) and (13), the values for *u* and *d* are taken from Table 1, while  $m_f = 1.08862171145 \cdot 10^{-28}$  is given by (4). Thus, we obtain for the proton:

$$m_p = m_f \cdot (2u_2 + d_2) + m_{gl} = 1.67241128117E-27 + 2.10642520635 \cdot 10^{-31} = 1.67262192369 \cdot 10^{-27} \text{ kg} \quad (12)$$

and for the neutron:

$$m_{ne} = m_f \cdot (u_3 + 2d_3) = 1.08862171145 \cdot 10^{-28} \cdot 15.3857623843 = 1.67492749791 \cdot 10^{-27} \text{ kg} \quad (13)$$

These are the values ( $m_p = 1.672\ 621\ 923\ 69(51) \cdot 10^{-27} \text{ kg}$ ,  $m_{ne} = 1.674\ 927\ 498\ 04(95) \cdot 10^{-27} \text{ kg}$ ) according to the CODATA 2018 reports [7]. According to this model, the neutron is most likely entirely composed of one *up* and two *down* quarks, since any possible gluonic remainder lies within the limits of numerical uncertainty; we therefore conclude that it is effectively absent in the neutron.

In other words, by employing the fundamental limit, we obtain constituent quarks that eliminate the need for the explicit inclusion of gluons and additional “exotic,” pion-mediated interactions within the nucleon (with pions in this model already appearing after the first iteration, which is not discussed here in detail).

The *non-cohesion* and *cohesion* limits, as well as the corresponding masses, can be expressed in the standard system of units [**m**, **kg**] by multiplying them by the values of  $r_f$  and  $m_f$  from (3) and (4). The constituent quark masses obtained from the second and third iterations of expression (9b), however, can be more conveniently used in dimensionless form for determining the forces within nucleons.

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