About Nature of Nuclear Forthes

The question of the nature of nuclear forces has become particularly urgent after discovery of neutron-proton composition of nuclei.
Currently, it is assumed that the attraction between nucleons in nuclei arises due to the fact that they exchange special particles - gluons, which cause a strong interaction.
This article proves that the attraction between protons and neutrons can be explained by the well-known quantum mechanical e_ect, which was _rst described about a hundred years ago.
This article provides evidence that the well-known quantum mechanical effect, which was described almost a hundred years ago, is responsible for the attraction between particles in nuclei.
This attraction e_ect occurs when two protons exchange an electron (in this case, a relativistic one). At that we can discard gluons and get the opportunity to quantify the defect of the mass of nuclei.
Keywords:
proton
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electron
light nuclei
heavy nuclei
defect of mass
1
Abstract

1 Introduction

The main problem of nuclear physics is the mystery of the nature of the forces acting between the particles in the nucleus.
This became especially relevant after the discovery of the neutron-proton composition of nuclei.
The _rst attempt to describe the structure of atoms was a model created by J.J. Thomson and called with English humor as plum pudding model.
Later, the liquid drop model was created by N.Bohr and Ya.Frankel and the shell model of M.Geppert-Mayer and H.Jensen.
They were followed by generalized, rotational, superuid, cluster, statistical, optical, and vibrational nuclear models.
Such a variety of models indicates scientists' dissatisfaction with the state of the theoretical description of atomic nuclei.
The most important problem that nuclear physics must solve is to determine the nature of nuclear forces.
Modern nuclear physics assumes that a strong interaction is responsible for the attraction between nucleons. It arising from the fact that quarks forming nucleons exchange special particles - gluons.
However, this way does not make it possible to calculate mass defects of atomic nuclei with some accuracy.
Below we will consider another approach to solving the problem of the binding energy of nuclei, in which these calculations can be done.
The basis of this new approach to the problem of coupling of nucleons is the mechanism described by the classics of quantum mechanics almost a hundred years ago.
V.Heitler and F.London described the occurrence of attraction between protons

at their electron exchange [1].
In order to describe the attraction that arises between nucleons due to such an e_ect, it is necessary to take into account that in this case the electron must be relativistic [2].
When solving this problem, the neutron must be considered as a composite particle. It gives possibility to obtain a fairly accurate estimate of all the basic properties of the neutron - mass, magnetic moment, decay energy.
This approach to constructing a neutron model is the _rst important step
2
to solving the problem of nuclear forces.

2 Electromagnetic model of neutron

2.1 Neutron and the quark model

Several theoretical models built in the twentieth century need to be reviewed.
The reason for this is their incompleteness or disagreement with the measurement data [3].
So the quark model can be replaced by a model describing the excited states of particles [4].
According to the Gell-Mann model, quarks, which make up elementary particles, carry fractional electric charges.
In the 60s, many experimental physicists unsuccessfully tried to _nd particles with a fractional charge.
A way out was found. To explain the failure to _nd fractional charges, the phenomenon of con_nement was suggested, which imposes a ban on the observation of quarks in a free state.
At that, it is clear that con_nement removes quarks from subordination to the Gilbert principle [5], since in this form the model claims to be scienti_c, without con_rming its data with measurements.

2.2 Electromagnetic model of neutron

Due to the lack of necessary experimental data, theoretical physicists in the 30s of the last century formed the opinion that both - proton and neutron - must be considered as elementary particles [6].
Let's consider neutron as a corpuscle, similar to a Bohr hydrogen atom, consisting of proton around which electron rotates at a short distance. The electron motion near proton must be relativistic.

2.3 The interaction of relativistic electron with proton

Let's assume that in the neutron model we are considering, an electron with a rest mass of m_e and a charge of e rotates around a proton in a circular orbit whose radius is R_e with a velocity of v_e ! c. (Fig.(1)).
3
Figure 1: A system consisting of a heavy (relativistic) electron and a proton. Both revolve around a common center of mass.
At that, it is necessary to take into account the relativistic e_ect of electron mass growth, since we initially assume that it moves at a speed close to the speed of light:
m_e
= m_e; (1)
where the relativistic factor
 =
1 p
1 _2
(2)
and _ = v
c .
In this case, the proton cannot be considered at rest. It will rotate around the common center of mass with heavy electron.

For the ratio of the mass of a relativistic electron to the mass of a proton,
we introduce the parameter:
=
m_e
M_p=
q
1 □ $\__2$
p
: (3)
Using the condition of equality of pulses, we obtain that $\__p$ = # and therefore
radii of orbits of the electron and proton:
R_e =
R_{ep}
1 + #
; R_p =
R_{ep}#
1 + #
: (4)
Where R_{ep} = R_e + R_p.
In this case the relativistic factor of electron is equal to
 =
#
p
1 □ $\#_2$
M_p
m_e
: (5)

2.3.1 Larmor's theorem
The peculiarity of proton motion along a circle of radius R_p described by Larmor's
theorem [7].
According to it, in a frame of reference rotating with proton, a magnetic
_eld acts determined by proton gyromagnetic ratio
H_L =

_ e
$2M_pc$
: (6)
Where _ =2.79 is the proton magnetic moment in units of Bohr magnetons.
The proton magnetic moment under the action of this _eld turns out to be
oriented perpendicular to the plane of rotation.
2.3.2 Quantization of equilibrium orbit
We will proceed from the fact that, just as for an electron orbit in a hydrogen
atom, the stability condition of a relativistic orbit can be written in the form of
equality 2_R_e, that is:
2_R_e = n$__{dB}$: (7)
Where n is integer number
and
$\__{dB}$ =
2_~
m_ec
(8)
is de Broglie wavelengths.
Thus, based on this assumption, we can write the condition for the electron
orbit stability:
$\_^c$

R_e
=
#
n
p
1 □ $\#^2$
M_p
m_e
=

n
(9)
Where $\_{c}$ = ~
$m_e c$ is the reduced Compton length.

2.3.3 The kinetic energy of rotating electron

The kinetic energy of relativistic electron:
E^e
$_{kin}$ = (□ 1) _ $m_e c^2$ (10)
As electron can be ultrarelativistic
E^e
$_{kin}$ _ _ $m_e c^2$ (11)
5
Centrifugal force applied to electron:
F_1 = m_e[![!;R_e]] =
$m_e c^2$
R_e
(12)
The proton kinetic energy
E^p
$_{kin}$ =

_
1
p
1 □ $\#^2$
□ 1

_
_$M_p c^2$ (13)
The rotated electron creates a magnetic _eld. Its energy gives additional contribution to the full electron kinetic energy
E_ =
_I
2c
; (14)
As the electron motion is quantized, the related magnetic ux
_ = $\_{0}$ =
2_~c
e
: (15)
As the electron ring carries current
I =
ec
2_R_e
; (16)
we have
$E_{\_e}$ =
e^2

Re
1
2_
_c
Re
=
1
2n
$m_e c^2$: (17)
The force creating by this _eld tends to break the ring of current
F_2 =

2n
$m_e c^2$
Re
: (18)
The magnetic energy of rotated proton is signi_cantly less:
$E_{\_p}$ =
p
2 _ $\#^2$
p
1 $\#^2$
$\_M_p c^2$: (19)
The corresponding force does not a_ect on the electron equilibrium orbit as it is applied to proton.
Thus, the electron has the total kinetic energy
E_
$_{kin}$ = E^e
$_{kin}$ + $E_{\_e}$ =
_
1 +
1
2n
_
$m_e c^2$: (20)
6
2.3.4 The Coulomb interaction in the system of relativistic electron + proton
The energy of Coulomb interaction between relativistic electron and proton is equal to [7],x24:
E_C =
e^2
R_{ep}
=
__c
$R_e(1 + \#)$
$m_e c^2$: (21)
Where _ = e^2
~c is the _ne structure constant.
Therefore, between these particles acts the Coulomb force
F_3 =
e^2
R^2
ep
=
_

$(1 + \#)^2$
$\_{c}$
R_e
$m_e c^2$
R_e
: (22)

2.3.5 The proton magnetic _eld acting on electron

The proton has two magnetic moments. The own proton magnetic moment:

$\_{p} =$
_e~
$2M_p c$
(23)

and the magnetic moment created by its rotation:

$\_{0p} =$
$e\#R_p$
2
(24)

and in the result the energy of this interaction:

$E\_ =$
e
$2R^2_e$
□
$\_{0p}$ □ $\_{p}$
_
: (25)

At that, magnetic moments $\_{p}$ and $\_{0p}$ should be directed oppositely to reduce the energy of the system.

The magnetic force of proton on rotating electron is equal to:

$F_4 = e\_$
_
$\_{0p}$
R^3_e
□
$\_{p}$
R^3_{ep}
_
=
= e
_
$\_{0p}$
R^3_e
□
$\_{p}$
$R^3_e (1 + \#)^3$
_
=
=
$m_e c^2$
R_e
_
$\#^2$
2

$$\square \; \_p \; (1+\#)^3 \quad \frac{\#}{2n\sqrt{1 \,\square\, \#^2}} \quad \frac{\#}{2n\sqrt{1 \,\square\, \#^2}} \quad \frac{M_p}{m_e} : \qquad (26)$$

The electron magnetic moment does not participate in this interaction, since the generalized momentum (spin) of the electron's orbit turns out to be zero and there is no direction for the chosen orientation of the electron's magnetic moment.

2.3.6 The equilibrium electron orbit

The condition for the formation of an equilibrium electron orbit is the absence of forces acting on electron:

$$\sum_{i=1}^{4} F_i = 0: \qquad (27)$$

Taking into account Eq.(9) and simplifying the sum of Eqs.(12),(22),(26) we obtain:

$$\left(1+\frac{1}{2n}\right) \square \; \frac{\#}{n\sqrt{1 \,\square\, \#^2}} \frac{M_p}{m_e} \; \frac{1}{(1+\#)^2} + \frac{\#^2}{2} \; \square \; \frac{2n(1+\#)^3}{\#\sqrt{1 \,\square\, \#^2}} = 0: \qquad (28)$$

2.4 The neutron in its basic state

A relativistic electron+proton pair can exist in a ground state with minimal energy at n = 1:

1 +
1
2
□
_
#
p
1 □ $\#^2$
$\_M_p$
m_e
__
1
$(1 + \#)^2$ +
$\#^2$
2
□
_
$2(1 + \#)^3$
#
p
1 □ $\#^2$
_
= 0: (29)

After simple transformations, we obtain

3
2
□ _
_
1
$(1 + \#)^2$ +
$\#^2$
2
□
_
$2(1 + \#)^3$
m_e
M_p
_
= 0: (30)

From here

= 0:1991 (31)

and

R_e = 1:2413 _ $10^{□13}$cm (32)

2.4.1 Spin of neutron

The spin of a neutron can be calculated by adding up the spin of proton, its moment of the generalized pulse and the moment of the generalized pulse of the electron current ring.

The electron generalized momentum is

S_{0e} =
h
R_e _
n
m_ec □
e

c
A_e
oi
(33)
8
The scalar form of it is
$S_{0e} = m_e c R_e$
_
3
2
□ _
_
1
(1 + #)
□
1 □ $#_2$
2
+ _
$\_{p}$
$(1 + #)_2$
m_e
$\_M_p$
__
: (34)
If to use values # and R_e which was obtained before, we have
$S_{0e} = 0$: (35)
Therefore, the total spin of these particles is 1/2, since it is created by proton.
The fact that the spin of the electron ring is zero plays an important role in the formation of the equilibrium state of the system.
As $S_0 = 0$ the own spin and magnetic moment of electron are devoid of orientation direction in space.
They fall out of the balance equations and, as a result, may not be taken into account at all in this task.

2.4.2 Mass of neutron

When calculating the summary mass of particle composed from proton and electron, it should be taken into account that to the sum of their masses of rest must be added their relativistic kinetic energy and the mass defect resulting from the potential energy of their internal interaction must be subtracted.
Let's calculate these contributions.
Kinetic energy of electron and proton After summing Eqs.(11),(13),(17) and (19) at n=1 we have
E(kin) =
#
p
1 □ $#_2$
"
1 +
_
1
p
1 □ $#_2$
□ 1
_ p
1 □ $#_2$
#
+

_
1
2
+
p
2#
_#
_$M_p c^2$ (36)
Potential energy of electron and proton When summing Eqs.(21) and (25) at n=1 we obtain
E(pot) =
_M_p
m_e
_
1
1 + #
+
$\#^2$
2
_
1
1
$(1 + \#)^3$
_
$\__p$
_#
p
1 $\#^2$
___
#
p
1 $\#^2$
$\_^2$
_$M_p c^2$:
(37)
The neutron mass At that the total mass of proton and electron is
$M_{e+p} = m_e + M_p +$
E_0
c^2 (38)
9
Where E_0 is the total energy of composed particle
E_0 = E(kin) E(pot) =
=
#
p
1 $\#^2$
"
1 +
_
1
p
1 $\#^2$
 1
_ p
1 $\#^2$
#

+
_
1
2n
+
p
2#
_#
_M_pc^2
_M_p
nm_e
_
1
1 + #
+
$\#^2$
2
_
1
1
$(1 + \#)^3$
_
_
n _ #
p
1 $\#^2$
___
#
p
1 $\#^2$
_2
_M_pc^2
(39)
Hence it turns out

$E_0 = 2{:}04$ _ m_ec^2 (40)

The summary kinetic and potential energy must be released at the decay of the particle.

This value is in agreement with data of measurement (Tab.1).

2.4.3 The magnetic moment of neutron

To calculate the particle magnetic moment is necessary to _nd the sum of magnetic moments of orbital currents of electron and proton and add the own proton magnetic moment.

$\_{0}$ =
$e\_{e}R_e$
2
+
$e\_{p}R_p$
2
=
eR_{ep}
2
$(1 \#^2)$
$(1 + \#)$
=
eR_{ep}

2
(1 □ #): (41)
Let's express this moment in Bohr's magneton $\_B$
$\_0$ =
$\_0$
$\_B$
= □
(1 □ $\#_2$)
p
1 □ $\#_2$
#
: (42)
At # = 0:1991 we obtain
$\_0$ _ □4:7269 (43)
The summing of it with the proton magnetic moment gives
$\_{total}$ =
"
□
(1 □ $\#_2$)
p
1 □ $\#_2$
#
+ 2:79
#
_ □1:9341: (44)
It is in well agreement with the tabular value
$\_{neutron}$ = □1:91304273: (45)

2.5 The excited states of neutron

Like a Bohr atom, neutron can have excited states with n > 1.
10

n	E_{kin} / c^2	E_{pot} / c^2	M_{total} Eq.(39)	experimental data	$\_ = \frac{M_{exp}□M_{calc}}{M_{exp}}$
n=1	$702m_e$	$700m_e$	$1839m_e$	M_{n0} = $1837m_e$	0.001
n=2	$879m_e$	$778m_e$	$1938m_e$	$M_{\_0}$ = $2183m_e$	0.11
n=3	$2103m_e$	$1740m_e$	$2200m_e$	$M_{\_0}$ = $2335m_e$	0.06

Table 1: The comparison of calculated particle mass values with measurement data

2.5.1 The excited state with n=2

In this case, Eq(28) is converted to:
1 +
1
2 _ 2
□
_
#
2
p
1 □ $\#_2$
$\_M_p$
m_e
__
1
$(1 + \#)_2$

_
+
+

_
#
2
p
1 □ #2
_Mp
me

__
#2
2
□

_
2 _ 2(1 + #)3
#
p
1 □ #2

_
= 0:
(46)

It gives

= 0:263: (47)

2.5.2 The excited state with n=3

In this case, we have

1 +
1
2 _ 3
□

_
#
3
p
1 □ #2
_Mp
me

__
1
(1 + #)2

_
□
□

_
#
3
p
1 □ #2
_Mp
me

__
#2
2
□

_
2 _ 3(1 + #)3

#
p
1 □ #2
_
= 0
(48)
and
= 0:479: (49)
Calculated values of masses and magnetic moments of neutron and its excited states for comparison with the measurement data are given in Table.(1) and Tab(2).
The agreement of these values gives reason to believe that neutral _- and _-hyperons are excited states of neutron [4].
11
n # _0 _total experimental.
Eq.(42) Eq.(44) data
n=1 0.1991 -4.727 -1. 9367 _n0 = □1:9130427 _ 0:0000005
n=2 0.263 -3.4147 -0.6247 __0 = □0:613 _ 0:004
n=3 0.479 -1.4121 1.3779 __0
_
= 1:61 _ 0:08
Table 2: Comparison of calculated values of magnetic moments with measurement data

2.6 Discussion

The obtained agreement of theoretical estimates and experimental data indicates that the neutron cannot be considered as an elementary particle [8].
Its feature is that the neutron mass is greater than the sum of the rest masses of a proton and an electron, despite the presence of a mass defect. This is because the proton and electron forming the neutron are relativistic, and their masses are much higher than their rest masses.
As a result, neutron decay occurs with the release of energy.
The main advantage of the electromagnetic neuron model discussed above is that it is the only theory that gives predictions of the basic properties of the neutron consistent with the experiment.
Gilbert's postulate makes it possible not to consider other models (and in particular the quark model of the neutron) because they cannot describe the measurable properties of the neutron.
The most important, necessary and quite su_cient argument for the reliability of the electromagnetic neutron model discussed above is that the measurements fully con_rm it.
Nevertheless, it is important for understanding that a standard theoretical apparatus was used for its construction.
The methodology that has been used to make estimates at a super_cial glance may not contribute to the perception of the results for those scientists who are accustomed to the language of relativistic quantum physics.
It is generally believed that the inuence of relativism on the behavior of an electron in a Coulomb _eld should be carried out on the basis of Dirac theory.
However that is not necessary in the case of calculating of the magnetic moment of the neutron and its decay energy.
12
However, when obtaining estimates of the neutron magnetic moment and its decay energy, this is not necessary.
_ All relativistic e_ects, which are described by terms with a relativistic factor
1 □ v2
c2
_□1=2

in this case compensate each other and as a result completely fall out.

Since in our model the neutron radius R_0 is proportional to the Planck constant $\hbar$, the neutron itself can be considered a quantum object.

But since the coe_cient

$$\left(1 - \frac{v^2}{c^2}\right)^{-1/2}$$

is not included in the de_nition of the radius R_0, the neutron cannot be considered as a relativistic particle.

This makes it possible to _nd the equilibrium of the system from the balance of forces, as can be done in the case of non-relativistic objects and thus calculate the magnetic moment of the neutron and its decay energy.

When estimating the neutron lifetime, another situation arises and it is not possible to get a correct estimate of lifetime in this way.

3 The one-electron bond between two protons and the simplest molecule

3.1 The one-electron bond between two protons

For the _rst time, the quantum mechanical problem of protons coupling in a molecular hydrogen ion was solved by W. Heitler and F. London in 1927 [1].

Let's take a closer look at a quantum system consisting of two protons and one electron [9].

In this quantum system there are two protons and one electron. If protons are spaced over a large distance, then this system consists of a hydrogen atom and a proton.

Let's put the hydrogen atom at the origin, then the energy operator and the ground state wave function have the form:

$$H_0^{(1)} = -\frac{\hbar^2}{2m}\nabla_r^2 - \frac{e^2}{r}; \quad \varphi_1 = \frac{1}{\sqrt{\pi a^3}} e^{-\frac{r}{a}} \qquad (50)$$

When the hydrogen atom is at the point R, then respectively

$$H_0^{(2)} = -\frac{\hbar^2}{2m}\nabla_r^2 - \frac{e^2}{|\vec{R} - \vec{r}|}; \quad \varphi_2 = \frac{1}{\sqrt{\ldots}}$$

$$\dot{a}_3 e^{-|\vec{R}-\vec{r}|/a} \quad (51)$$

13

If protons are fixed, then the Hamiltonian of the system takes the form:

$$H = -\frac{\hbar^2}{2m}\nabla_r^2 - \frac{e^2}{r} - \frac{e^2}{|\vec{R}-\vec{r}|} + \frac{e^2}{R} \quad (52)$$

The system energy is equal to the ground state energy E_0 if one proton is removed to infinity. The wave function in this case satisfies the stationary Schrodinger equation:

$$H_0^{(1;2)}\varphi_{1;2} = E_0\varphi_{1;2} \quad (53)$$

In the zero approximation, we will look for a solution in the form of a linear combination of basic functions:

$$\psi = a_1(t)\varphi_1 + a_2(t)\varphi_2 \quad (54)$$

Here the coefficients are $a_1(t)$ and $a_2(t)$ depend on time, and the desired function satisfies the Schrodinger equation:

$$i\hbar\frac{d\psi}{dt} = (H_0^{(1;2)} + V_{1;2})\psi; \quad (55)$$

where $V_{1;2}$ is the Coulomb energy of the system.

The standard conversion procedure results in a system of equations

$$\begin{aligned} i\hbar\dot{a}_1 + i\hbar S\dot{a}_2 &= E_0\left\{(1+Y_{11})a_1 + (S+Y_{12})a_2\right\} \\ i\hbar S\dot{a}_1 + i\hbar\dot{a}_2 &= E_0\left\{(S+Y_{21})a_1 + (1+Y_{22})a_2\right\}. \end{aligned} \quad (56)$$

Where the notation of the overlap integral of wave functions is introduced

$$S = \int \psi_1^*\psi_2\, dv = \int$$

_ _2
$_1$dv (57)
and matrix elements
Y_{11} =
1
E_0
Z
_ _1
V_1 $_1$dv
Y_{12} =
1
E_0
Z
_ _1
V_2 $_2$dv
Y_{21} =
1
E_0
Z
_ _2
V_1 $_1$dv
Y_{22} =
1
E_0
Z
_ _2
V_2 $_2$dv
(58)
Taking into account the symmetry
$Y_{11} = Y_{22}$ $Y_{12} = Y_{21}$; (59)
14
after performing simple operations, we get a system of equations
i~(1 + S)(_a_1 + _a_2) = _(a_1 + a_2)
i~(1 □ S)(_a_1 □ _a_2) = _(a_1 □ a_2)
(60)
Where
_ = E_0
n
(1 + S) + Y_{11} + Y_{12}
o
_ = E_0
n
(1 □ S) + Y_{11} □ Y_{12}
o (61)
This leads to two solutions
$a_1 + a_2 = C_1$exp
_
□i
E_0
~
t
_
exp
_
□i
_1

$$\left.\frac{}{\hbar} t\right)$$

$$a_1 - a_2 = C_2 \exp\left(-i \frac{E_0}{\hbar} t\right) \exp\left(-i \frac{\epsilon_2}{\hbar} t\right) \quad (62)$$

where

$$\epsilon_1 = E_0 \frac{Y_{11} + Y_{12}}{(1 + S)} \qquad \epsilon_2 = E_0 \frac{Y_{11} - Y_{12}}{(1 - S)} : \quad (63)$$

From here

$$a_1 = \frac{1}{2} e^{-i\omega t} \left(e^{-i\frac{\epsilon_1}{\hbar} t} + e^{-i\frac{\epsilon_2}{\hbar} t}\right) \qquad a_2 = \frac{1}{2} e^{-i\omega t} \left(e^{-i\frac{\epsilon_1}{\hbar} t} - e^{-i\frac{\epsilon_2}{\hbar} t}\right) \quad (64)$$

and

$$|a_1|^2 = \frac{1}{2}\left(1 + \cos\left(\frac{\epsilon_1 - \epsilon_2}{\hbar} t\right)\right) \qquad |a_2|^2 = \frac{1}{2}\left(1 - \cos\right.$$

_
$_1$ □ $_2$
~
t
__ (65)
As
$_1$ □ $_2$ = $2E_0$
Y_{12} □ SY_{11}
1 □ S_2 (66)
under initial conditions
$a_1(0) = 1$ $a_2(0) = 0$ (67)
15
and
$C_1 = C_2 = 1$ (68)
or
C_1 = □_____C_2 = 1 (69)
that is, it turns out an oscillating probability of _nding an electron near each of the protons:
ja_1j_2 =
1
2
(1 + cos!t)
ja_2j_2 =
1
2
(1 □ cos!t)
(70)
Thus, an electron passes from one proton to another with a frequency of ! forming a degenerate system (hydrogen + proton).
The frequency ! corresponds to the energy of tunnel splitting, which occurs due to the jump of electron (Fig.2).
Thus, due to the electron exchange, mutual attraction arises between protons and leads to a decrease in their energy
_ =
~!
2
(71)
This attraction is a purely quantum mechanical e_ect. There is not analogical e_ect in classical physics.
Tunneling splitting and the energy of mutual attraction between protons have a dependence on two parameters:
_ = jE_0j _ _; (72)
where E_0 is energy of the undisturbed state of the system and the mutual distance between protons _. According to Eq.(66) this function has the form:
_ =
Y_{12} □ SY_{11}
(1 □ S_2)
: (73)
As the estimation of the exchange splitting _E shows, this e_ect decreases exponentially with increasing distance between protons in full accordance with the laws of particle passage through the tunnel barrier.
16
Figure 2: The potential pit with two symmetric states. Electron in the ground state can be either in the right or in the left part of the pit. The energy of undisturbed state is E_0. A tunnel transition from one pit to another causes splitting of the energy level and lowering of the split sublevel by _.

3.2 The molecular hydrogen ion

W. Heitler and F. London in 1927 calculate all parameters of this task [1].

They calculate the Coulomb integral:

$$Y_{11} = \left(1 - (1 + x)e^{-2x}\right); \quad (74)$$

the exchanging integral

$$Y_{12} = \left(x(1 + x)e^{-x}\right) \quad (75)$$

and the integral of overlaping

$$S = \left(1 + x + \frac{x^2}{3}\right)e^{-x}: \quad (76)$$

Where $x = \frac{R}{a_B}$ is the dimensionless distance between the protons.

With taking into account that the potential energy of hydrogen atom is equal to

$$E_0 = -\frac{e^2}{a_B} \quad (77)$$

and Eqs.(74)-(76), we havt

$$\varepsilon(x) = \frac{x(1 + x)e^{-x} - \left(1 + x + \frac{x^2}{3}\right)\left(1 - (1 + x)e^{-2x}\right)}{1 - \left(1 + x + \frac{x^2}{3}\right)^2 e^{-2x}} \quad (78)$$

The varying the function $\varepsilon(x)$ shows that at

$$x \simeq 1.3 \quad (79)$$

there is a minimum energy of the system

$$\varepsilon_{x=1.3} \simeq 0.43: \quad (80)$$

Permutations show that the mutual attraction of protons reaches a maximum at this minimum energy

$$\varepsilon_{max} \simeq 9.3 \times 10^{-12} erg: \quad (81)$$

This result coincides with the measurements only in order of magnitude. From measurements the energy of the rupture of this ion is close to 4.3×10^{-12} erg.

In order to achieve a better agreement between calculations and measurements, researchers vary the equations to the charge of the electron cloud.

This allows to get a good agreement of the calculations with the experiment, but this is beyond our interests, since we needed a simple and straightforward consideration of the e_ect.

4 Deuteron and other light nuclei

4.1 Deuteron

The electromagnetic model of neuron was discussed above. Based on this consideration, we get an opportunity to take a fresh look at the mechanism of interaction of particles inside a nucleus.

Neutron made up of proton and electron cloud surrounding it, together with a free proton make up an object similar to a molecular hydrogen ion.

The di_erence is that in this case the radius of the electron orbit is equal$R$ _ 10^{-13} cm since electron is relativistic (Eq.(32)).

Earlier the energy of electron in the composition of neutron was calculated (Eq.(40)):

$E_0 = 2{:}04$ _ $m_e c^2$ (82)

The energy of exchange has maximum at

$\_{max} = 0{:}43;$ (83)

when protons are placed on distance $x = \frac{R}{R_e} = 1{:}3$ (Eq.(79)).

The binding energy in nuclei is usually expressed in atomic units of mass, which have the international designation u. With what

$1u = 1{:}6605402$ _ $10^{-24}g:$ (84)

18

Figure 3: Schematic representation of deuteron. The dotted line schematically shows the possibility of a relativistic electron jumping from one proton to another.

In these units, the attractive energy of two protons exchanging a relativistic electron is equal to:

$\_0 = \_{max}E_0$ ' $10^{-3}u:$ (85)

Measured deuteron mass defect

$\_M_D = M_p + M_n - M_d$ _ $2{:}3414$ _ $10^{-3}u$ (86)

Where

$M_p = 1{:}007276466621$ u, $M_n = 1{:}00866491560u$ and $M_d = 2{:}0136u$ are masses of proton, neutron and deuteron, respectively.

Thus, we can see that the quantum-mechanical estimate of the deuteron binding energy (Eq.(85)), as in the case of a molecular hydrogen ion, agrees with the experimentally measured value (Eq.(86)), although in both cases, their coincidence, is not very accurate.

4.2 Helium isotopes

Fig.(4) shows schematically the energy bonds in the nucleus of ^3_2He. From it we can seen that there are three paired interactions of protons. Therefore, it should be assumed that the binding energy of this nucleus should be equal to the triple binding energy of the deuteron (Eq.(86)):

$\_M_{He3} = 3$ _ $\_M_D$ _ $7{:}02$ _ $10^{-3}u:$ (87)

19

Figure 4: Schematic representation of ^3_2He. Dotted lines schematically represent the possibility of a relativistic electron jumping from one proton to another.

Figure 5: Schematic representation of ^4_2He. Dotted lines schematically represent the possibility of a relativistic electron jumping from one proton to another.

20

The experimentally measured mass defect of this nucleus is equal to

$\_M(He3) = 2M_p + M_n - M_{He3} = 8{:}29$ _ $10^{-3}u:$ (88)

Thus, it can be assumed that the calculated value of the mass defect of this nucleus is consistent with the measured value.
As can be seen from Fig.(5), in this nucleus, two electrons participate in six pair interactions of protons _M$_d$. For this reason, the binding energy of the isotope 42
He should be equal to:
_M_ = 2 _ 6 _ _M$_D$ _ 28:1 _ 10□3u: (89)
The measured value of mass defect of this nucleus is equal to
_M_ = 2M$_p$ + 2M$_n$ □M_ = 30:4 _ 10□3u: (90)
Such agreement of these values can be considered quite satisfactory.

4.3 Beryllium isotopes

Figure 6: The schematic representation of energy bonds in the Be-8 core. Dotted lines represent the possibility of a relativistic electron jumping between protons.

Figure 7: Schematic representation of energy bonds in the Be-9 core. Dotted lines represent the possibility of a relativistic electron jumping between protons.

A comparison of the binding energies of beryllium isotopes points the way to calculating mass defects of heavy nuclei.

Figure 8: Comparison of calculated values of the mass defect of light nuclei with the measurement data.

Comparing the mass of the core 84
Be with twice the mass of the alphaparticle,
we can conclude that this core must be unstable.
Indeed, measurements show that the isotope 84
Be is very short-lived. Its
lifetime is approximately 10□17sec.
However, if neutron attaches to nucleus 84
Be and the result is nucleus 94
Be
(Fig.7). This nucleus is stable and its mass defect is equal to:
_M(Be9) = 4 _M$_p$ + 5 _M$_n$ □M$_{Be9}$ = 60:25 _ 10□3u: (91)
The mass defect of alpha-particle according to Eq.(89) is equal to 12 __M$_d$.

isotope	M	_M	N$_d$	_M = N$_d$ _ _M$_D$	_M□_M / _M
	u	10□3u		10□3u	%
21 D	2.01355	2.3414	1	-	
32 He	3.01493	8.2878	3	7.0242	15
42 He	4.001506179	30.377	12	28.097	7.5
84 Be	8.00530510	58.46	24	56.194	3.9
94 Be	9.0121822	60.248	26	60.876	1

Table 3: Comparison of the calculated values of the defect of the mass of light nuclei with the measurement data.

Two alpha particles respectively create a mass defect 24 _ _M$_d$. To this value, we need to add a doubled deuteron defect of mass 2 _ _M$_d$, since the electron

of an additional neutron connecting alpha-particles (Fig.7) has the ability to
transfer to free protons of neighboring alpha-particles. As a result, we get the
total mass defect of 94
Be
_M(Be9) = 26 _ _M_D = 60:88 _ 10□3u: (92)
Good agreement of this estimate with the experimental value (Eq.(91)) suggests
that neutron can bind alpha-particles together, playing the role of a kind of glue.
23

5 Mass defects of heavy nuclei

Given the peculiarity of the structure scheme of nucleus 94
Be (Fig.7), it can
be assumed that other stable heavy nuclei may have a similar architecture and
represent them as "crystals" consisting of alpha-particles "glued" by neutrons
(Fig.9). We can imagine an "unit cell" of such a three-dimensional "crystal"
Figure 9: Schematic representation of the "crystal" models of a heavy nucleus
in which alpha-particles are "glued" together by neutrons
as alpha-particle, which is connected by neutrons with other alpha-particles
located along the three axes of this "crystal" (Fig.10).
In order to obtain a numerical estimate of the binding energy of heavy nuclei,
we introduce the following notation:
A is the total number of nucleons in the nucleus,
Z is an even number of protons,
N_n = A □ Z is the number of neutrons,
N_ = Z=2 is the number of alpha-particles,
N_{glue} = N_n □ Z - excess number of neutrons "gluing" alpha-particles.
24
Figure 10: "Elementary cell" three-dimensional "crystal" models of a heavy
nucleus in which alpha particles are "glued" together by neutrons.
At that, the mass defect of an isotope:
_M_{isotop} = M_p _ Z +M_n _ N_n □M_{isotop}: (93)
Where M_{isotop} is measured mass of an isotope.
The deuteron mass defect was determined earlier (Eq.86):
_M_D = 2:3414 _ 10□3u: (94)
Let's introduce the parameter q, which denotes the di_erence between the
number of alpha-particles in the nucleus and the number of neutrons that alphaparticles
"glue" together:
q = N_ □ N_{glue}: (95)
For those isotopes for which these numbers match, this parameter
q = 0: (96)
For these isotopes, the "unit cell" has a mass defect
_M(alpha) = _M_ + 6 _ _M_D = 18 _ _M_D (97)
and the total defect of the mass of such nucleus
_M(nucl) = 18 _ _M_D _ N_: (98)
The number of alpha-particles may exceed the number of neutrons "gluing"
them, since one neutron can "glue" a di_erent number of alpha-particles. Therefore,
for many isotopes q 6= 0.
25
In some nuclei, where there is a shortage of neutrons, alpha-particles lose
"gluing" neutrons along one of axes of the "crystal". For such nuclei, the mass
defect
_M(nucl) = _M_D [18(N_{alpha} □ q) + 16q] : (99)
Hence the contribution to the binding energy that occurs in the nucleus
between protons due to the exchange of a relativistic electron:
_M(nucl) = 9:3644 _ 10□3 _ (Z + A=2) u: (100)

6 Correction for Coulomb interaction

For a more accurate description of the total binding energy in nuclei, it is necessary to introduce a correction for the Coulomb interaction of nucleons.
It is generally assumed that the nuclei consist of a substance with the same density

$_n$ _ 10^{14} g=cm^3 (101)

The mass of a spherical body with radius R of such substance

4_
3
$_nR^3_n$
= AM_N (102)

Here M_N and A are the mass of nucleon and their number in nucleus.
From here we can determine the radius of the core with constant density $_n$

R_n = 1:59 _ $10^{□13}$ $_3$
p
A (103)

The Coulomb energy of such spherical nucleus, taking into account the _eld created by it in outer space

E_Q =
3
5
Z^2e^2
R_n
= 8:72 _ $10^{□7}$ Z^2
$_3$ p
A
erg (104)

From here, turning to atomic units of mass, we get

E_Q = 5:85 _ $10^{□4}$ Z^2
$_3$ p
A
u (105)

Thus, the total mass defect of nuclei is equal to

$\_M_n$ = 9:36 _ $10^{□3}$
_
Z + A=2 □ 0:062
Z^2
$_3$ p
A
_
u; (106)

which is in good agreement with the measurement data (Fig.11).

Figure 11: Comparison of calculated mass defects of nuclei (Eq.(106)) with experimentally measured values of _M.

7 Conclusion

Based on the fact that the calculated binding energies for many c nuclei are in good agreement with the measurement data, it can be assumed that the strong interaction is a purely quantum mechanical e_ect described above.
This gives a physical explanation to Hideki Yukawa's hypothesis that nuclear forces should be described by a shielded potential that cuts o_ their action at

short distances, and also allows us to calculate its magnitude.
It seems that the model discussed above, in which the nuclei consisting of protons and electrons, can be considered a kind of development of the idea of Sir Joseph John Thomson, who suggested a similar structure of the atom at the

very beginning of the last century.
After the discovery of neutrons, Thomson's model began to seem of purely historical interest.
Figure 12: Sir Joseph John Thomson, who created in 1903 a model in which atoms consisted only of positive charges and electrons, called "pudding with raisins".
Somewhat later, already in the 30s of the last century, I.E. Tamm consider the e_ect of electron exchange as the possibility of explaining nuclear forces [10].
However, soon the model of exchange of _-mesons, and then gluons, began to prevail in nuclear physics.
This is understood. In order to explain the magnitude and range of the nuclear forces, the exchange must be carried out by a heavy particle with a small spatial wavelength.
However, the models of _-meson or gluon exchange turned out to be unproductive.
These models could not quantify the mass defects even of light nuclei.
The above considered model is simple and gives a measurement-consistent estimate.
This clearly proves that the so-called strong interaction in nuclei is a mani-

Figure 13: Stable nuclei with _M > 0 lie to the left of the observed stability boundary, indicated by a vertical line. In nuclei for which _M < 0, alpha-decay is possible.
festation of the quantum mechanical e_ect of attraction between protons which arises due to their exchange of a relativistic electron.
The simple approach described above to calculating defects in the mass of nuclei gives a good match with the measurement data.
This suggests that earlier theories of nuclear forces, such as the drip-model or the shell-model of nuclei, in terms of calculating the binding energy of nuclei can be considered of historical interest.
Using the data on the mass defect of nuclei, it is possible to raise the question of for which nuclei alpha-decay is possible and which are not.
Let the original nucleus AZ
X have mass M(AZ
X).

Let's denote the di_erence in the masses of the products of its hypothetical alpha-decay and its mass
_M = M(A□4
Z□2X) +M_ □M(AZ
X): (107)
If _M > 0, alpha-decay of such nuclei is impossible. In Fig.(13), these nuclei lie to the left of the observed stability boundary, indicated by a vertical line.
In those nuclei for which _M < 0, alpha-decay is possible, and they lie to the right of the stability boundary in Fig.13. At the same time, the further they lie from this boundary, the larger the modulus of _M is obtained, i.e., the greater the decay energy and, in accordance with the Sergent rule, the shorter their lifetime.
This can be considered proof that there are no reasons for the emergence of islands of stability among transuranic nuclei, and all the activity to search for them among superheavy nuclei looks devoid of a physical basis.
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