The Origin of the Generalized EMC Effect

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Abstract: Here, using the Scale-Symmetric Theory (SST), we show that the sizes of the EMC effect per nucleon in different nuclei depend on a mean of local inertias for the nuclei and that the generalized EMC effect concerns the virtual nuclear field of nucleons. We described also the shadowing region, the dip, and the two plateaux. We predict that for nuclei at least such heavy as iron, there should be a point/strong-signal for the Bjorken x = 3.2 and the EMC ratio 4.8. We show that the dependence of nuclear binding energy on mass-number is a result of modification of the virtual nuclear weak field and that the proton magnetic and electric polarizability radii play the key role.

1. Introduction

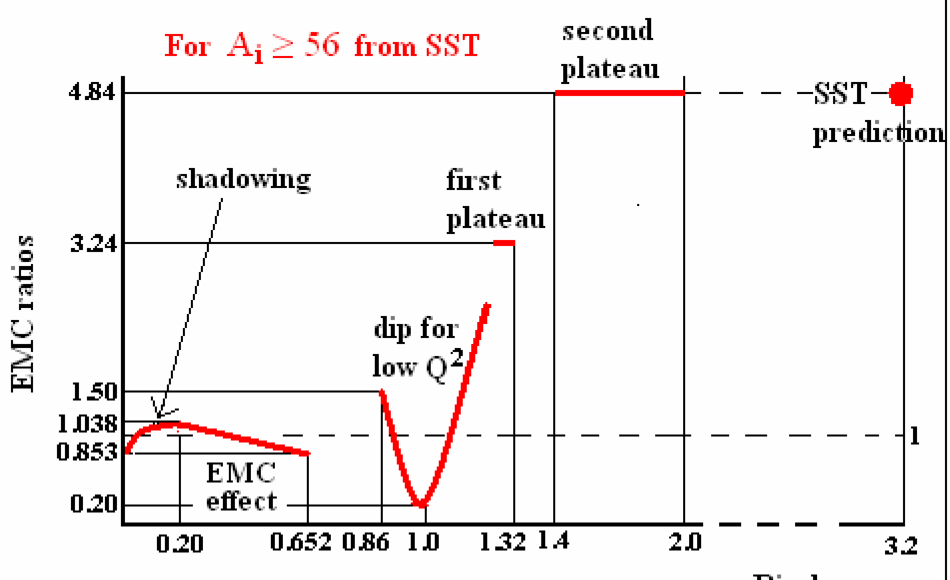

Fig.1
Dependence of the EMC ratios on the Bjorken x for nucleon in heaviest nuclei in deep inelastic scattering on the basis of SST.

The average binding energy of nucleons inside atomic nuclei is very low in comparison with the energy transferred in deep inelastic scattering (DIS) reactions that probe nucleons, so the cross sections for nucleons in nuclei and for free nucleons should be practically the same.

But they are not. It is the European-Muon-Collaboration (EMC) effect, the very important unsolved problem in physics since 1983 [1].

Here, using the Scale-Symmetric Theory [2], we show that the EMC effect and the dependence of nuclear binding energy on the **mass-number** A_i (it is the sum of protons and neutrons in atomic nucleus) follow from modifications of the virtual nuclear field of nucleons.

We show that the dependence of the EMC ratios on the Bjorken x for nucleon in atomic nucleus in DIS can be described by the generalized curve presented in Fig.1. Our theoretical results are fully consistent with the averaged experimental data presented in [3]. We additionally predict that there should be a point/strong-signal for the Bjorken $x = 3.2$ and the EMC ratio $R_{EMC} = 4.84$, so our model can be experimentally verified.

The EMC effect is an anomalous region in which the EMC ratio (the ratio of cross section of nucleon in atomic nucleus to cross section of free proton) decreases with increasing the Bjorken x.

SST shows that a nucleon consists of the core composed of the spin-1/2 torus/electric-charge with the equatorial radius equal to $A = 0.6974425$ **fm** (it is responsible for the nuclear strong and electromagnetic interactions) and of the central (scalar) spacetime condensate $Y = 424.12176$ **MeV** responsible for the nuclear weak interactions. Outside the core, there is the relativistic pion on the Titius-Bode orbit for the nuclear strong interactions (its radius is $A + B = 1.19928$ **fm**).

From the model of dynamic supersymmetry for atomic nuclei and experimental data [4] follows that in the lighter nuclei, there dominate the almost free alpha particles denoted by 2p2n (where p denotes proton while n neutron) and the bound $(2p2n)_{bound}$ alpha particles (it is a half of the 4p4n cuboid), so the 4p4n cuboids as well. In the heavier nuclei, there dominate the 3p5n and 4p4n cuboids. The internal structure of atomic nuclei on the main path of stability is described in [2].

The more and more protons in heavier and heavier atomic nuclei force the 4p4n → 3p5n transitions. But contrary to the 4p4n, in the 3p5n cuboid, there is one unpolarized neutron that practically is not bound with the other 7 nucleons. It causes that the distance between the bases in the 3p5n cuboid is larger than in 4p4n. It is possible because the virtual field concerning the nuclear weak interactions has two quantized ranges which are the proton magnetic and electric polarizability radii [5] – they are equal to A and $A + B$, respectively, and they are the equatorial radius of the core of baryons and the radius of the orbit for the nuclear strong interactions on which the relativistic charged pion in nucleons is placed.

We start from following remarks.

*The nucleons in a nucleus interact in such a way the number of the pn pairs was biggest.

*From the model of dynamic supersymmetry for atomic nuclei follows that the interactions in nuclear structures (i.e. N, 1p1n, 2p2n, 3p4n, 4p4n and 3p5n [2]) are practically saturated so we neglect the interactions between the structures because they appear sporadically. The mean binding energy per nucleon from interactions of such structures is very low.

*Bigger nuclei contain more protons so to decrease the electrostatic repulsion there is forced the transition from 4p4n to 3p5n.

*The two bases in the 4p4n cuboid and one in 3p5n, <u>in the plane of the squares</u> behave as the free alpha particle (its binding energy is $E_{b,alpha} = 28.30$ **MeV**), so the binding energy per nucleon that follows from the nuclear strong and electromagnetic interactions is $E_{alpha} = 7.0746$ **MeV/nucleon** [2].

*The nucleons in pn pair, when placed on the same shell [2], interact strongly and electromagnetically because the spins of the nucleons are perpendicular to the shell. On the other hand, the nucleons in pn pair, when placed on different shells, interact due to the nuclear weak interactions because their spins lie on the same direction.

*Consider the nuclear weak interactions. The nuclear weak coupling constant, $\alpha_{w(p)} = 0.0187229$, is defined as follows

$$\alpha_{w(p)} = G_w Y^2 / (c \hbar) , \tag{1}$$

where G_w is an analog to the gravitational constant, and Y is the mass of the spacetime condensate in the centre of the core of baryons that is responsible for the nuclear weak interactions [2].

When the nucleons are polarized (their spins lie on the same direction) then both kinetic and potential energies of exchanged the spacetime condensates Y transform into the binding energy. Then the weak binding mass per pn pair is defined as follows

$$m_{b,pn} = (\alpha_{w(p)} \hbar / c) (1 / R) = 6.5861 \cdot 10^{-45} / R \text{ [kg] per pn pair} . \tag{2}$$

Formula (2) is valid for polarized nucleons in direction of their spin. Formula for unpolarized nucleons is derived in [2] (see Section **C2** in [2]).

From (2), for the distance between the nucleons in a pn pair equal to A (in direction of the nucleon spins), we have that the binding energy is

$$E_{b,pn\text{-}weak,A} = 5.2972 \text{ MeV per pn} , \tag{3}$$

whereas for $A+B$ is

$$E_{b,pn\text{-}weak,A+B} = 3.0806 \text{ MeV per pn} . \tag{4}$$

*Here we show that when we take into account the nuclear weak interactions in the direction of the nucleon spin in the 8-nucleon cuboids and the proton magnetic and electric polarizability radii then the theory of the binding energy is much simpler and leads to correct results.

*Consider the 4p4n cuboid (or the $(2p2n)_{bound}$ squares bound with other structures via the four nuclear weak interactions in directions of the polarized spins of the 4 nucleons) – see Fig.2.

Assume that the height of the 4p4n cuboid that follows from the nuclear weak interactions is A – it is the equatorial radius of the core of the nucleons but also the proton magnetic polarizability radius [5]. Due to the surface tension of the virtual weak field, such virtual field has spherical symmetry. Then the total binding energy for the 4p4n is

$$E_{4p4n,total} = 2\ E_{b,alpha} + 4\ E_{b,pn\text{-}weak,A} = 77.79\ \mathbf{MeV}\ , \tag{5}$$

whereas for the $(2p2n)_{bound}$ square is

$$E_{2p2n(bound),total} = E_{4p4n,total} / 2 = 38.90\ \mathbf{MeV}\ , \tag{6}$$

so per one nucleon we obtain

$$E_{4p4n} = E_{4p4n,total} / 8 = E_{2p2n(bound),total} / 4 = 9.72\ \mathbf{MeV/nucleon}\ . \tag{7}$$

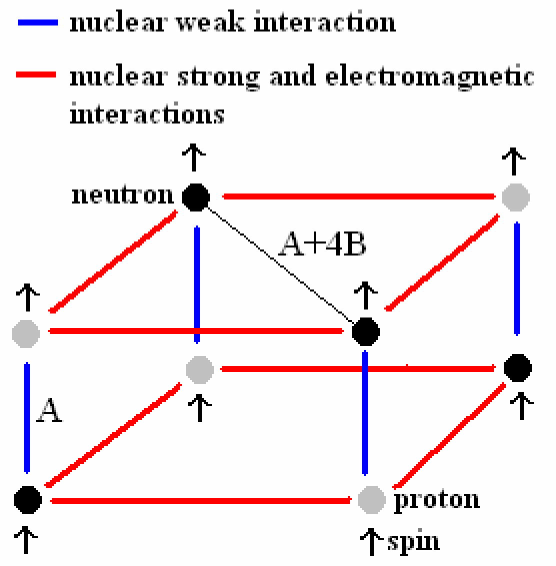

Fig.2. The 4p4n cuboid.

*Consider the 3p5n cuboid – see Fig.3.

From Fig.3, due to the practically unbound one <u>unpolarized</u> neutron (it is surrounded by three neutrons), follows that in some approximation there are 6 interactions with the binding energy equal to E_{alpha} and only 3 nuclear weak interactions. It causes that the interactions between the bases of the 3p5n cuboid are weakened so distance between them should be larger than in 4p4n.

The next larger quantized distance in nucleons is A + B [2] that is also the proton electric polarizability radius [5], so we assume that it is the height of the 3p5n cuboid.

Then the total binding energy for the 3p5n is

$$E_{3p5n,total} = 6\ E_{alpha} + 3\ E_{b,pn\text{-}weak,A+B} = 51.69\ \mathbf{MeV}\ , \tag{8}$$

so per one nucleon we obtain

$$E_{3p5n} = E_{3p5n,total} / 8 = 6.46\ \mathbf{MeV/nucleon}\ . \tag{9}$$

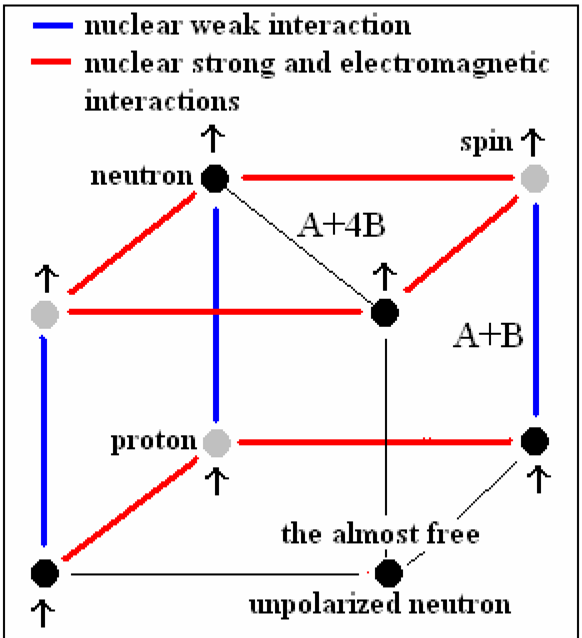

Fig.3. The 3p5n cuboid.

*We know that from the supersymmetry in nuclear structure follows that energy of interactions of our cuboids, due to the saturation, is low in comparison with their internal binding energy. It suggests that distance between them should be the radius of the last orbit for the nuclear strong interactions (A+4B) or the quantized photonic radius of the protons (A+8B). The mean distance is A + 6B = 3.7085 **fm**. It leads to conclusion that our cuboids occupy cubes with the side equal to (A+6B). On the assumption that the mean mass of nucleon in atomic nucleus is about 931 **MeV**, we obtain that the mean mass density of nuclear matter in nuclei in which dominate the cuboids, i.e. for $A_i \geq 56$, should be an invariant and it is

$$(\text{Mass-density})_{\text{Mass-number}\geq 56} = (8\cdot 931\ \text{MeV}) / (A + 6\,B)^3 = 2.60\cdot 10^{17}\ \mathbf{kg/m^3}\ . \quad (10)$$

This value is consistent with experimental data so it additionally validates our model.

Emphasize that ranges of the virtual field of nucleons in atomic nuclei are different but the global/effective mass density of the heavier nuclei should be an invariant!

*SST shows that the cores of baryons are indestructible – they can be destroyed only in annihilations of the core-anticore pairs. It is the reason that the SST nuclear plasma composed of the baryonic cores is unstable. The baryonic core, in the SST nuclear plasma composed of the baryonic cores packed to maximum, occupies a cuboid with the sizes equal to 2A, 2A and 2A/3 [2]. On the other hand, mass of the charged baryonic core is about 0.7274 **GeV** [2] so the SST lower limit for energy density needed to create the plasma composed of the nucleon cores is

$$(\text{Mass-density})_{\text{Lower-limit,plasma}} = 0.7274\ \mathbf{GeV} / (2A\cdot 2A\cdot 2A/3) = 0.80\ \mathbf{GeV/fm^3}\ . \quad (11)$$

The needed temperature, because of the nuclear virtual field composed of the virtual $W_{(+),d=4}W_{(-),d=4}$ pairs, is $T = W_{(+-),d=4} \approx 162.01257$ **MeV** [5].

These two theoretical values (density and temperature) also are consistent with experimental data so it additionally validates our model concerning the nuclear binding energies.

*In Fig.4, we present for selected atomic nuclei the dependence of the ratio of the number of the 3p5d cuboids to the number of the alpha particles bound with other nucleons due to the nuclear weak interactions (see Table **C3** in [2]) on the **mass-number**.

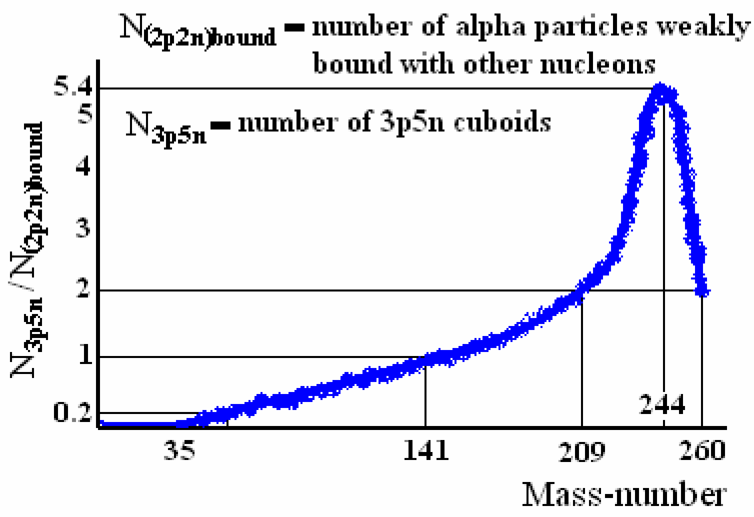

Fig.4. Dependence of the ratio $N_{3p5n} / N_{(2p2n)bound}$ on the Mass-number.

2. Binding energies of selected nuclei with $A_i \geq 56$

The $_{26}Fe^{56}$ consists of 5 the 4p4n cuboids and of 2 the 3p5n cuboids (i.e. there are 26 protons and 30 neutrons and the number ratio of the cuboids is 0.4) so for the binding energy per nucleon we obtain

$$E_{Fe} = (5\ E_{4p4n,total} + 2\ E_{3p5n,total}) / 56 = 8.79\ \textbf{MeV/nucleon}\ . \qquad (12)$$

The $_{103}Lr^{256}$ consists of 7 the 4p4n cuboids and of 25 the 3p5n cuboids (i.e. there are 103 protons and 153 neutrons and the number ratio of the cuboids is ~3.6, i.e. about 9 times higher than in Fe), so for the binding energy per nucleon we obtain

$$E_{Lr} = (7\ E_{4p4n,total} + 25\ E_{3p5n,total}) / 256 = 7.17\ \textbf{MeV/nucleon}\ . \qquad (13)$$

Our results are consistent with experimental data.

3. Binding energies of selected nuclei with $8 \leq A_i \leq 56$

In such nuclei, there can be the almost free alpha particles $_2He^4$ ($E_{b,alpha}$ = 28.30 **MeV**) or the $(2p2n)_{bound}$ structures ($E_{2p2n(bound),total}$ = 38.90 **MeV**) so the mean is 33.60 **MeV**.

When the mass-number increases from 8 to 56 then there is more and more the bound $(2p2n)_{bound}$ structures instead the almost free 2p2n structures (it is very important to

understand the size of the EMC effect), so the binding energy per nucleon increases from about 7 **MeV/nucleon** to 8.79 **MeV/nucleon**.

Calculate the binding energy per nucleon for a mean nucleus, for example, for ${}_{16}S^{32}$ (there should be 4 the almost free alpha particles and 4 the bound $(2p2n)_{bound}$ structures)

$$E_S = (4\, E_{b,alpha} + 4\, E_{2p2n(bound),total}) / 32 = 8.40 \textbf{ MeV/nucleon} . \quad (14)$$

It is consistent with experimental data.

4. Binding energies of selected light nuclei

In [2], we calculated the binding energies per nucleon in deuteron (~2.198 **MeV** per the pn pair) and in the free alpha particle (~7.07046 **MeV/nucleon**).

It is surprising that we obtain also the correct value for the binding energy of the deuteron ${}_1H^2$ with polarized spins of the nucleons on the assumption that there is the nuclear weak interaction on distance A+B* = 1.66674 **fm**, where B* = 0.969294 **fm** is the second solution for the distance between the second and first the Titius-Bode orbits for the nuclear strong interactions (see Section **2.7** in [2]). Formula (2) gives

$$E_{deuteron} = 2.2166 \textbf{ MeV} . \quad (15)$$

In ${}_1H^3$ and ${}_2He^3$ there are only the two nuclear weak interactions of the three polarized nucleons (all spins are on the same direction). On the assumption that one interaction has the range A whereas the second one has the range A+B, we obtain

$$E \text{ (for both } {}_1H^3 \text{ and } {}_2He^3) = (E_{b,pn\text{-}weak,A} + E_{b,pn\text{-}weak,A+B}) / 3 = 2.79 \textbf{ MeV/nucleon} . \quad (16)$$

For ${}_3Li^7$ we have

$${}_3Li^7 \equiv {}_2He^4 + {}_1H^3 , \quad (17)$$

so we have

$$E\, ({}_3Li^7) = (E_{b,alpha} + 3 \cdot 2.79 \textbf{ MeV/nucleon}) / 7 = 5.24 \textbf{ MeV/nucleon} . \quad (18)$$

5. The magic atomic nuclei

In the magic nuclei, the concentric shells are fully filled so the global structure is more ordered – it causes that the interactions between the cuboids are a little stronger so binding energy per nucleon in the magic nuclei is a little higher.

6. The EMC effect

The Bjorken x we define as follows

$$x = (M_i / N)^2 , \quad (19)$$

where M_i^2 represents the squared mass/energy of the dominating particle/object in the virtual field of nucleons created due to DIS, and N = (p + n) / 2 is the mean mass of nucleon.

Due to DIS, there are produced some characteristic virtual objects with the masses $\pm M_i$. Emphasize that a virtual object consists of a particle with positive mass and with a "hole" in the SST absolute spacetime with negative mass, so in our model appears the squared mass M_i^2. Due to such a resonance, i.e. DIS → $\pm M_i$, number density of virtual particles in each nucleon increases the same. It forces the oscillations of the nucleon virtual field that causes emission of virtual energy, so range/radius of the virtual field is reduced. Next, for increasing Q^2, because in DIS of nuclei the absorbed energy by nucleus is higher in nuclei with higher mean inertia, frequency of the oscillations increases and is higher in nuclei with higher mean inertia, so range of the virtual field in nucleons in such nuclei decreases faster, so the slope for cross section is steeper (see Figures 5, 6 and 7). For the M_i two times higher than the resonance energy, i.e. for $2M_i$, we should observe a second increase in the number density of the virtual particles.

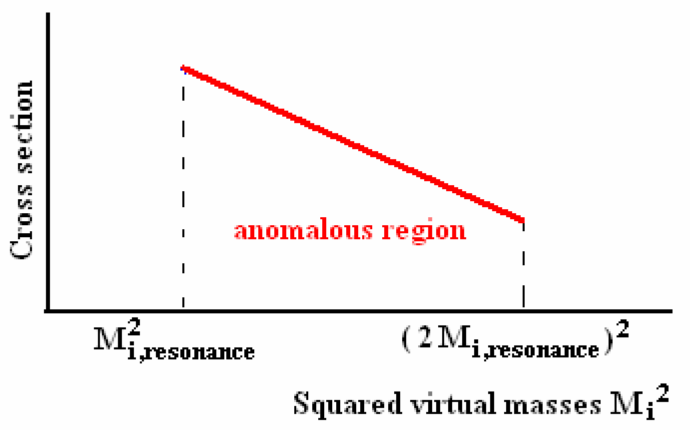

Fig.5. Anomalous region for cross section.

Calculate the lower and upper limits for the Bjorken x for the EMC effect on the assumption that in a nucleon, mass of the virtual particles with the positive mass is $M_{i,resonance} = Y$. From (19) we have

$$0.204 \le x \le 0.816\,, \tag{20}$$

i.e. $x_{lower} = 0.204$ and $x_{upper} = 0.816$.

Emphasize that the anomalous region defined by the interval (20) is the result of the additional virtual nuclear field that forces its oscillations.

Reduction of the volume of the virtual nucleon weak field per nucleon in deep inelastic scattering is more effective in nuclei with higher mean inertia concerning the different 6 stable structures (i.e. 4p4n, 3p5n, 3p4n, 2p2n, 1p1n, N), not rather in nuclei with higher global/effective densities. Inertia of such structures is directly proportional to number of nucleons they consist of. Then the mean inertia of a nucleus depends on number densities of the stable structures – there are the 8-, 7-, 4-, 2-nucleon structures and the almost free nucleons.

For higher local inertia, the incoming energy (due to DIS) is absorbed to a greater extent therefore the higher frequency of the virtual-field oscillations reduces the range of the nucleon virtual field more effectively. This means that in the anomalous region, the EMC ratio (i.e. σ_A/σ_o, where σ_A is the cross section of nucleon in nucleus with the **mass-number** equal to A_j, and σ_o is the cross section of the virtual field of free proton) decreases with increasing the Bjorken x – see Fig.6.

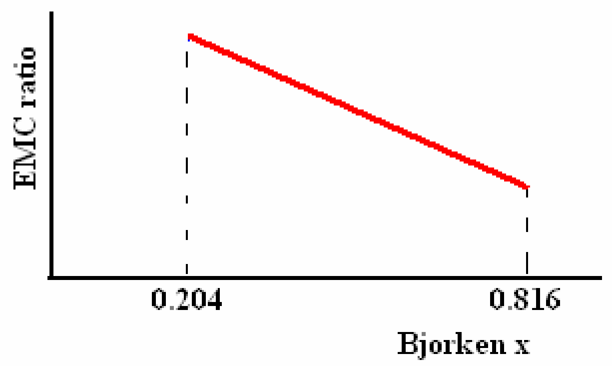

Fig.6. The EMC effect.

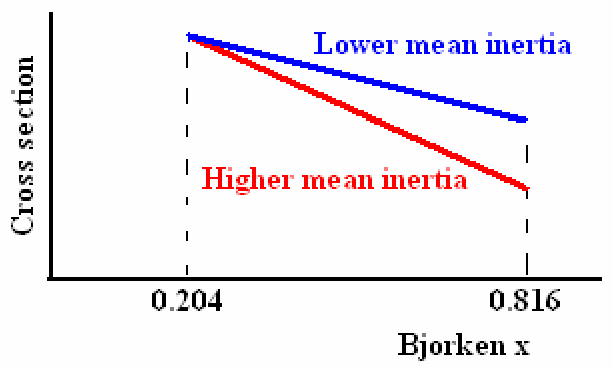

Fig.7. Cross sections for nucleon in nuclei with different mean inertia.

It also means that due to the described mechanism, the cross section of a nucleon in the EMC region should decrease with increasing Bjorken x but for a nucleon in nucleus with higher mean inertia, the slope should be steeper (see Fig.7).

Here the cross section is defined as

$$\sigma = \pi r^2 , \tag{21}$$

where r denotes radius of a virtual field.

Calculate the EMC ratio for a nucleon in which the nucleon virtual field absorbs or emits a virtual mass/energy equal to $\Delta M_{virtual}$. We assume that the virtual field, due to the surface tension, has spherical symmetry. Then mass is directly proportional to r^3, so from (21) we obtain

$$R_{EMC} = \sigma_A / \sigma_o = (R_A / R_o)^2 = \{[(M_{virtual} \pm \Delta M_{virtual}) / M_{virtual}]^{1/3}\}^2 =$$

$$= (1 \pm \Delta M_{virtual} / M_{virtual})^{2/3} . \qquad (22)$$

On the other hand, the Bjorken x has following changed value

$$x \rightarrow x_{new} = [(M_i \pm \Delta M_{virtual}) / N]^2 . \qquad (23)$$

In free nucleon, the virtual nuclear weak field is characteristic for the interior of the core of baryons so the radius/range is equal to $R_o = A$. The weak cross section of the free proton is defined as follows

$$\sigma_o = \pi A^2 = 1.528 \ \mathbf{fm^2} . \qquad (24)$$

Notice that the EMC ratio for free nucleon is

$$R_{EMC,o} = \sigma_o / \sigma_o = 1 . \qquad (25)$$

Due to DIS, we should add to the free-nucleon virtual field its electroweak mass M_{ew} that has the maximal value at $x = 0.204$

$$\Delta M_{virtual,x=0.204} = M_{ew} = (\alpha_{w(p)} + \alpha_{em}) N = 24.4 \ \mathbf{MeV} , \qquad (26)$$

where α_{em} is the fine-structure constant [2].

Here the initial virtual mass at the Bjorken $x = (Y / N)^2 = 0.204$ is $M_{virtual} = Y$ (it is also mass of the additional virtual field in $x = 816$ (i.e. $2Y - Y = Y$)), so from formula (22) we obtain

$$R_{EMC,x=0.204} = (1 + \Delta M_{virtual,x=0.204} / Y)^{2/3} = 1.038 . \qquad (27)$$

We use this value to scaling the EMC effect. It is the enhancement above the $R_{EMC,o} = 1$ around the Bjorken $x_{lower} = 0.204$.

Calculate the maximal change in virtual field for the nuclear structures with maximal mean inertia, i.e. for the 8-nucleon cuboids (i.e. 4p4n and 3p5n).

In such structures, a nucleon can emits the virtual fundamental gluon loop (FGL) in the plane of its plane, say in direction of the x-axis or y-axis, or the virtual neutral pion in direction of the nucleon spin, i.e. in direction of the z-axis (the neutral pion is the pseudoscalar so such emission conserves the nucleon spin). Then the mean maximal virtual energy emitted per nucleon is

$$M_{mean,maximal} = (2\ m_{FGL} + \pi^o) / 3 = 90 \ \mathbf{MeV} . \qquad (28)$$

Such emission decreases range of the additional nucleon virtual field (it is Y at the Bjorken $x_{upper} = 0.816$) so also volume. Then the EMC ratio decreases to its lowest value. From (22) we have

$$R_{EMC,8\text{-}nucleons} = (1 - M_{mean,maximal} / Y)^{2/3} = 0.853 . \qquad (29)$$

Such a phenomenon causes that the x_{upper} decreases to (see formula (23))

$$x_{upper} \rightarrow x_{new} = [(2Y - M_{mean,maximal}) / N]^2 = 0.652 . \quad (30)$$

The maximal EMC slope is

$$(dR_{EMC} / dx)_{8\text{-nucleons}} = (R_{EMC,8} - R_{EMC,x=0.204}) / (x_{new} - x_{lower}) =$$

$$= (0.853 - 1.038) / 0.448 = -0.413 . \quad (31)$$

Due to the different inertias of the nuclear structures, the slope of the EMC effect should be lower for nuclear structures containing less the nucleons. We assume that the relation is directly proportional, so we obtain

$$(dR_{EMC} / dx)_{7\text{-nucleons}} = 7\, (dR_{EMC} / dx)_{8\text{-nucleons}} / 8 = -0.361 . \quad (32)$$

$$(dR_{EMC} / dx)_{4\text{-nucleons}} = 4\, (dR_{EMC} / dx)_{8\text{-nucleons}} / 8 = -0.207 . \quad (33)$$

$$(dR_{EMC} / dx)_{2\text{-nucleons}} = 2\, (dR_{EMC} / dx)_{8\text{-nucleons}} / 8 = -0.103 . \quad (34)$$

We see that the slope for deuteron is –0.103 (it is consistent with experimental data [6]) and for the alpha particle is –0.207 (it is consistent with experimental data as well [3]).
For nuclei containing different structures we have

$$(dR_{EMC} / dx)_{A} = \Sigma\, n_k\, (dR_{EMC} / dx)_{k\text{-nucleons}} / A_i , \quad (35)$$

where n_k denotes number of nucleons in structures containing k nucleons.

Table 1 *Slopes of the EMC effect for selected nuclei from SST*

Z symbol A_i	4p4n	3p5n	3p4n	2p2n	1p1n	1N	**Slope of the EMC effect**
1 H 1						**1**	**0**
1 H 2, D					**1**		**– 0.103**
1 H 3, 2 He 3					**1**	**1**	**– 0.069**
2 He 4				**1**			**– 0.207**
3 Li 7				**1**	**1**	**1**	**– 0.148**
4 Be 9				**2**		**1**	**– 0.184**
6 C 12	**1**			**1** **3**			**– 0.344** **– 0.207** **mean –0.276**
16 S 32	**2**			**4**			**– 0.310**
20 Ca 40	**4**			**2**			**– 0.372**
20 Ca 48	**4**			**4**			**– 0.344**
26 Fe 56	**5**	**2**					**– 0.413**
50 Sn 120	**5**	**10**					**– 0.413**
102 No 256	**6**	**26**					**– 0.413**

For example, in ^9Be, there are two the 2p2n structures and one almost free neutron, so we have

$$(dR_{EMC} / dx)_{Be9} = 8\,(-0.207) / 9 = -0.184\,. \qquad (36)$$

For nuclei with $A_i \geq 56$, we obtain -0.413 so there is some saturation that follows from the domination of the 8-nucleon structures.

The selected results we present in Table 1.

We see that the slope of the EMC effect does not depend on the nuclear mass-number A_i and for $A_i \geq 56$ it is constant, i.e. about -0.413. The EMC slope depends on mean inertia of structures a nucleus consists of.

Notice that nucleons in the cuboids and squares in a nucleus are already polarized and their interactions are practically saturated (i.e. the cuboids interact sporadically), so a spin polarization of the cuboids as a wholes by an external magnetic field should have a low influence on the EMC effect.

7. The second plateau and the predicted separated point in Fig.1

In the atomic nuclei (due to DIS), there can be created virtual fields with the masses of the hyperons.

The hyperons are created quickly due to the nuclear strong interactions and decay slowly due to the nuclear weak interactions (we do not take into account the neutral sigma hyperon). It means that initially the virtual field has cylindrical symmetry. In SST, we showed that the state $d=2$ (i.e. **radius** $= A + 2B = 1.7011$ **fm**) is responsible for the properties of the hyperons. It means that the radii of virtual field of all hyperons are: $A+2B$, $A+2B$, and the $A+B$ in direction of the spin, so the virtual weak field is extended to maximum. The mean radius is 1.534 **fm**, so the mean cross section is $\sigma = 7.391$ **fm**^{2}, so the EMC ratio for all hyperons is (see formula (24))

$$R_{EMC,plateau2} = 7.391\ \mathbf{fm}^2 / \sigma_o = 4.84\,. \qquad (37)$$

On the other hand, the M_i in the definition of the Bjorken x are the masses of the hyperons, so we obtain: for the lambda hyperon $x = 1.41$, for the sigma hyperons $x \approx 1.6$, for the ksi hyperons $x \approx 1.98$, and for the omega hyperon $x = 3.2$. We can see that there should be a plateau from $x \approx 1.4$ up to $x \approx 2.0$ and the separated point/strong-signal for $x = 3.2$.

Due to the predicted separated point/strong-signal with $R_{EMC,plateau2} = 4.84$ and Bjorken $x = 3.2$, we can verify our model.

8. The first plateau in Fig.1

The first plateau is for the non-relativistic real pions created inside nucleons. Emphasize that in nucleons, in the state $d=1$ (the radius is $A+B$) there is already the relativistic pion. The positive mass of virtual field is $M_i = N + \pi^{\pm,o}$. The mean radius of virtual field of nucleons in heavier nuclei is $A+B = 1.19928$ **fm**, so creation of the additional pion causes that the mean radius of the virtual field increases to

$$R = [(N + \pi^{\pm,o}) / N]^{1/3}\,(A + B) = 1.2551\ \mathbf{fm}\,. \qquad (38)$$

Such conditions lead to the first plateau extended from Bjorken $x = 1.31$ up to $x = 1.32$ with the EMC ratio equal to (there is $\sigma = \pi R^2 = 4.949$ $\mathbf{fm^2}$)

$$R_{EMC,plateau1} = 4.949\ \mathbf{fm^2} / \sigma_o = 3.24\ . \tag{39}$$

9. The dip in Fig.1

The minimum in the dip concerns the creation of virtual FGL by real nucleon so $M_i = N$, so the Bjorken $x = 1$. The radii of the emitted one virtual FGL are: $2A/3$, $2A/3$, and 0, so the mean radius is $R_{FGL,mean} = 0.310$ **fm**, so the R_{EMC} ratio for the FGL is (there is $\sigma = \pi R_{FGL,mean}{}^2 = 0.302$ $\mathbf{fm^2}$)

$$R_{EMC,FGL} = 0.302\ \mathbf{fm^2} / \sigma_o = 0.20 \tag{40}$$

and it is the minimum for the dip. For higher squared four-momentum Q^2, there are produced the entangled FGLs so the EMC ratio increases, i.e. the dip at $x = 1$ fills in.

The emitted real FGLs decrease the nucleon mass so the Bjorken x is lower than $x = 1$, while the not emitted real FGLs increase the Bjorken x, so it is higher than $x = 1$. Such is the origin of the dip in Fig.1.

Calculate the EMC ratio for almost free one real FGL. The FGLs collect at the mean distance equal to the electron radius of proton $r_{o(p),e} = 0.877$ **fm** [2]. The radius of virtual field is

$$R_{left} = [(N - m_{FGL}) / N]^{1/3}\ r_{o(p),e} = 0.8554\ \mathbf{fm}\ , \tag{41}$$

so the EMC ratio is (there is $\sigma = \pi R_{left}{}^2 = 2.299$ $\mathbf{fm^2}$)

$$R_{EMC,left} = 2.299\ \mathbf{fm^2} / \sigma_o = 1.50 \tag{42}$$

while the Bjorken x is

$$x_{left} = [(N - m_{FGL}) / N]^2 = 0.86\ . \tag{43}$$

Such values, i.e. $x = 0.86$ and $R_{EMC} = 1.50$, are for the left beginning of the dip.

The right side of the dip is for the real FGLs created inside nucleon at the mean distance $r_{o(p),e}$.

10. The shadowing region in Fig.1

The shadowing region is, due to DIS, for created virtual structures that are entangled with the virtual nuclear weak field. There appear resonances for masses characteristic for nucleons.

The $|\Delta E_{core}| = 14.978$ **MeV** is the binding energy of the core of baryons [2]. It is the “hole” in the SST absolute spacetime with the radius equal to the equatorial radius of the core of nucleons A. The positive energy from DIS equal to $-\Delta E_{core}$ fills the “hole” but because the binding energy must be negative, it forces the oscillations of the virtual field that decreases its radius. From (22) we obtain

$$R_{EMC} = (1 - |\Delta E_{core}| / Y)^{2/3} = 0.976\ , \tag{44}$$

and from (19) is

$$x = (|\Delta E_{core}| \,/\, N)^2 = 0.00026\,. \tag{45}$$

On the other hand, we know that the photoproduction absorption in deuteron starts from the Bjorken $x \approx 0.00026$. It looks as a resonance.

Calculate the Bjorken x and R_{EMC} for the maximal mean energy emitted by the nucleon virtual fields (we have $M_{mean,maximal} = 90$ **MeV** – see formula (28))

$$R_{EMC,minimum} = (1 - M_{mean,maximal} \,/\, Y)^{2/3} = 0.853\,. \tag{46}$$

$$x = (M_{mean,maximal} \,/\, N)^2 = 0.009\,. \tag{47}$$

Such values should be characteristic for the shadowing region for nucleon in heavy nuclei, i.e. the curve should go through such a point.

The oscillations in the shadowing region should quickly disappear with increasing the Bjorken x and at $x = 0.204$ such oscillations disappear. It means that the shadowing region is due to the phenomena concerning nucleons, i.e. it does not concern the mean inertias of nuclei.

11. The global results

Notice that from (22) follows that for emission of one neutral pion, π^o, we have

$$R_{EMC,pion} = (1 - \pi^o \,/\, Y)^{2/3} = 0.7745\,. \tag{48}$$

We use this value to scaling the magnitude a_2.

We define the magnitude of the plateau2 as follows

$$a_2 = R_{EMC}\,(\mathbf{plateau2}) \,/\, R_{EMC,pion}\,. \tag{49}$$

For the region with the Bjorken $x > 1$, the magnitude a_2 is a function of the nuclear **mass-number** because with increasing the Bjorken x, the range of the nuclear weak field increases from A for nucleons to $A+2B$ for hyperons, so cross section of the nuclear virtual field increases as well because there increases the R_{EMC} (**plateau2**).

Notice that the $A+2B$ state for hyperons is the ground state above the Schwarzschild surface for the nuclear strong interactions [2].

Emphasize also that the mean inertia per nucleon is invariant for $A_i \geq 56$, so there is an asymptotic behaviour of nucleons in such nuclei.

The maximum value for the a_2 magnitude is

$$a_2\,(\mathbf{maximum,}\ A_i \geq 56\,) = R_{EMC,plateau2} \,/\, R_{EMC,pion} = 6.25\,. \tag{50}$$

The minimum should be for nucleon

$$a_2\,(\mathbf{minimum,\ N}) = R_{EMC}\,(\mathbf{plateau2})_N \,/\, R_{EMC,N} = 1\,. \tag{51}$$

On the other hand, the slope of the EMC effect, $-dR_{EMC}/dx$, should be **zero** for proton and neutron, and should be the maximum for nucleon in nuclei with $A_i \geq 56$

$$(-dR_{EMC}/dx)_{maximum} = (1.038 - 0.853) / (0.652 - 0.204) = 0.413 . \qquad (52)$$

So with very good approximation we have

$$0 \leq -dR_{EMC}/dx \leq 0.413 . \qquad (53)$$

Our global results are collected in Fig.9 – they are consistent with experimental data [7].

Our formula for the dependence of the slope of the EMC effect on the a_2 magnitude of the plateau2 looks as follow

$$[-dR_{EMC}/dx]_{SST} = (a_2 - 1) \cdot 0.079 . \qquad (54)$$

It is consistent with experimental data – in [7], there is 0.079(6).

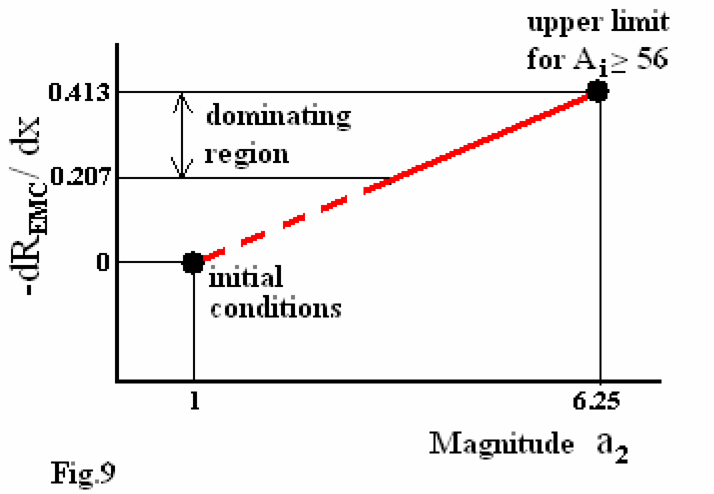

Fig.9
Dependence of the slope of the EMC effect on the magnitude of the plateau2.

12. Summary

The shadowing region in Fig.1, due to DIS, is because of the created virtual structures entangled with the virtual nuclear weak field – there appear resonances for masses characteristic for nucleons. The EMC region is due to the oscillations of virtual nuclear fields so there is emitted virtual energy (such processes are more intensive in regions with higher local inertia) so the EMC ratio decreases with increasing the Bjorken x. The dip is for the FGLs-nucleon interactions. The first plateau is for production of the real pions inside nucleon. The second plateau and the predicted separated point/strong-signal (so our model can be verified) are for production of additional virtual fields with positive masses equal to masses of the real hyperons. The consistency of the theoretical SST results with experimental data is perfect.

The EMC effect is the response of the virtual nuclear field of nucleon in atomic nucleus on deep inelastic scattering.

Our model for the EMC effect is not a full analogue to the electrons in a condense-matter state because the sources of the nuclear strong fields (i.e. the cores of baryons) in nucleons do not overlap even partly in the atomic nuclei. So the source of the strong interactions cannot be modified. The radius of the core along the axis of rotation is $A/3$ while the smallest distance between the nucleons in atomic nuclei in such direction is A, i.e. it is larger than $2(A/3)$. On the other hand, the equatorial radius of the core is equal to A whereas the smallest distance between nucleons in the plane of the equator is $(A + 4B)/2^{1/2}$, i.e. it is larger than $2A$.

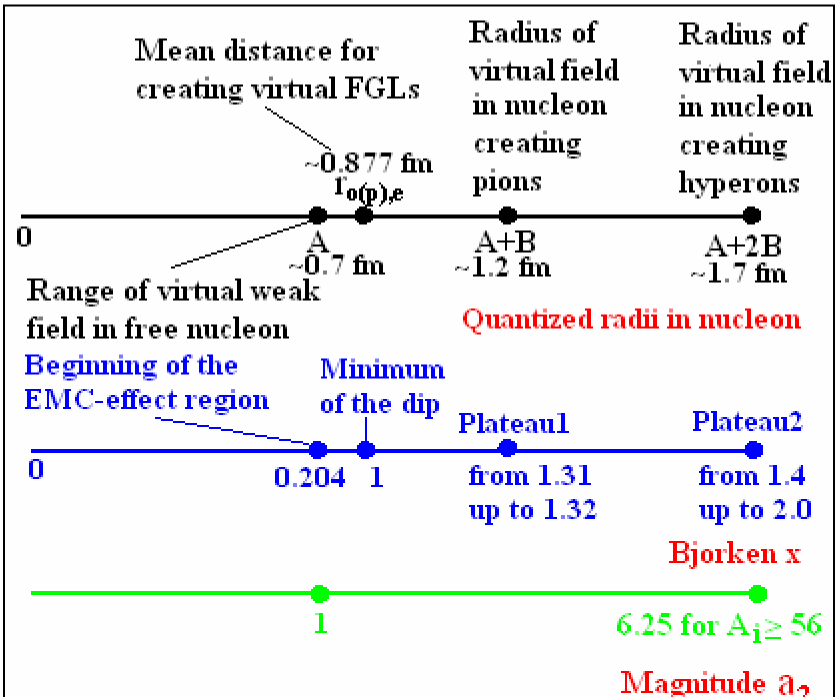

Fig.10. Summary.

Our theoretical energies of binding per nucleon for selected atomic nuclei very well reflect the experimental curve for all nuclei, so our model of the structure of nuclei and their internal interactions can be considered credible, which additionally makes our description of the generalized EMC effect more plausible.

Within SST, we already described the nuclear interactions via the strong-electromagnetic interactions when the height of the cuboids is $A+4B$ (there is $E_1 \sim \alpha_s^{NN,\pi}\alpha_{em}/(A+4B) = 0.03885$ [2]) and when the spin of the nucleons rotates 90 degrees. Here we showed that we obtain similar results for stable spin polarization, so involved energy is two times higher, via the nuclear weak interactions, when the height of the cuboids is a mean $R_{weak} = [(A+B)+A]/2$ (there is $E_2 \sim 2\alpha_{w(p)} / R_{weak} = 0.03948$). Such two different quantum states should lead to some oscillations of the heavier atomic nuclei. But we claim that in DIS, the quantum state described in this paper is the ground state because the nuclear weak interactions that are characteristic for the EMC effect can force such change in the structure of nucleons (notice that we have $E_2 \approx E_1 (1 + \alpha_{w(p)})$).

To fully explain the EMC effect and the nuclear binding energies, we need the atom-like structure and dynamics of baryons described in the Scale-Symmetric Theory, especially the quantized Titius-Bode orbits for the nuclear strong interactions. We

cannot do it within the quark model of hadrons. It is the reason that for 40 years the two basic problems were a puzzle.

The size of EMC effect depends on the mean inertias of nuclei that depend on number densities of the different nuclear structures in a nucleus, not on the global/effective densities of nuclei.

SST shows that local inertias for $A_i \geq 56$ practically do not depend on A_i because of the 8-nucleon cuboids that dominate. It causes that we should observe some saturation (an asymptotic behaviour) for such nuclei.

The most surprising fact is that the second plateau and the separated point in Fig.1 concern the virtual fields of hyperons.

In Fig.11 we show a "mirror" similarity between the shadowing region and the EMC-effect region. At the beginning of the first region and at the end of the second region for the nuclei with highest mean inertia, there appear the resonances for the additional energy of the virtual fields, i.e. the 90 **MeV**. But at the beginning of the shadowing region there is created virtual energy not entangled with nucleon while at the end of the EMC-effect region, the positive virtual energy is emitted by nucleon so mass of the nucleon decreases.

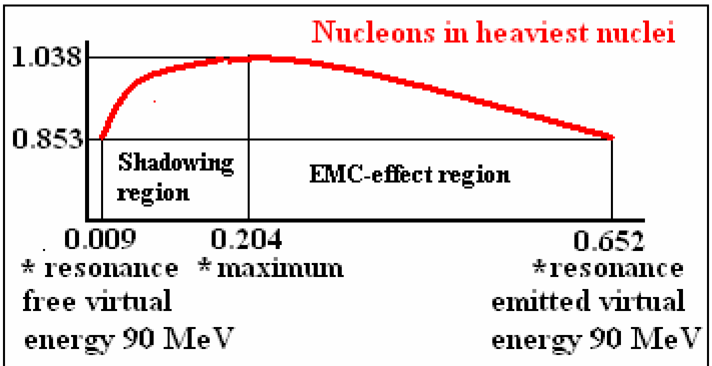

Fig.11. A mirror similarity of the shadowing region and the EMC-effect region

In our generalized model (graphically presented in Fig.1), there appear the characteristic masses concerning the baryons (p, n, masses of **hyperons**, Y ≈ 424 **MeV** concerning in SST the weak interactions, **pions** and m_{FGL} concerning the strong interactions and the binding energy of the core of baryons ΔE_{core}). It causes that our generalized model is unique and fully consistent with experimental data.

Why does the quark model largely mimic our atom-like structure of nucleons? The answer to this fundamental question results from the fact that the description of interactions is based on coupling constants, the values of which depend mainly on the masses/energies of the sources of the interactions and to a much lesser extend on other quantities. In the quark model, we have three *relativistic* spin-1/2 valence quarks (so we have big problems with calculating the nucleon spin) with relativistic masses of about 300 MeV each. On the other hand, in our model of nucleons, *there are also three main parts* with masses around 300, 400 and 200 MeV, but only one part is a fermion, one is a scalar, and the third part is a pseudoscalar. Only the pseudoscalar is a relativistic particle. As a result, the number of parameters in our model is about four times smaller than in QCD and the spin calculation within SST is a formality.

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