Magnetic Moment, Mass, Spin and Strangeness of Hyperons

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Abstract: The Scale-Symmetric Theory (SST) is the lacking part of the Theory of Everything. SST describes the succeeding phase transitions of the non-gravitating Higgs field, the atom-like structure of baryons, and many other basic problems. Here, within SST, we calculated the magnetic moments and precise masses of hyperons, their spin and strangeness. Obtained results are consistent or very close to experimental data.

1. Introduction

The foundations of the Scale-Symmetric Theory (SST), [1], lead to the atom-like structure of baryons [1A]. In baryons, there is the core and there are the Titius-Bode orbits for the nuclear strong interactions [1A]. The core is the modified black hole (there is not a singularity but there is the orbit with the spin speed equal to the speed of light in "vacuum" c) in respect of the strong interactions [1A]. The $d = 2$ orbit is the ground state outside the Schwarzschild surface for the nuclear strong interactions [1A]. This orbit/state is responsible for the properties of hyperons [1A].

We already described the approximate internal structure of hyperons [1A] (the values of the approximate masses are in MeV)

$$m_{\Lambda} = m_{neutron} + M_{(o),k=0,d=2} = 1115.3, \quad (1)$$
$$m_{\Sigma(+)} = m_{proton} + M_{(o),k=2,d=2} = 1189.6, \quad (2)$$
$$m_{\Sigma(o)} = m_{neutron} + M_{(o),k=2,d=2} = 1190.9, \quad (3)$$
$$m_{\Sigma(-)} = m_{neutron} + M_{(-),k=2,d=2} = 1196.9, \quad (4)$$
$$m_{\Xi(o)} = m_{\Lambda} + M_{(o),k=1,d=2} = 1316.2, \quad (5)$$
$$m_{\Xi(-)} = m_{\Lambda} + M_{(-),k=1,d=2} = 1322.2, \quad (6)$$
$$m_{\Omega(-)} = m_{\Xi(-o)} + M_{(o-),k=3,d=2} = 1674.4. \quad (7)$$

Following formula defines the masses $M_{(+-o),k,d}$ [1A]

$$M_{(+-o),k,d=2} = m_{W(+-o),d=2} + \sum_{d=0,1,2,4}^{d<2^k} dE_W , \quad (8)$$

where $k = 0, 1, 2, 3$ whereas $E_W = 25.213$ MeV. The k and d determine quantum state of particle having a mass $M_{(+-o),k,d}$. The mass of a hyperon is equal to the sum of the mass of a nucleon and of the masses calculated from (8). The $m_{W(+-o),d=2}$ is the relativistic mass of pion in the $d = 2$ state defined by the Titius-Bode law for the strong interactions ($m_{W(+-),d=2}$ = 181.704 MeV whereas $m_{W(o),d=2} = 175.709$ MeV).

The number of the relativistic W pions in the $d = 2$ state, i.e. in the ground state above the Schwarzschild surface for the strong interactions, taken with the sign "–" defines the strangeness of a hyperon.

The Scale-Symmetric Theory, [1A], defines as well a probability that the y proton is composed of the charged core H^+ and relativistic neutral pion $W_{(o),d=1}$ and a probability that $1\text{-}y$ is composed of H^o and $W_{(+),d=1}$. From the Heisenberg uncertainty principle follows that the probabilities y and $1\text{-}y$, which are associated with the lifetimes of protons in the above-mentioned states, are inversely proportional to the relativistic masses of the W pions

$$y = m_{pion(+-)} / (m_{pion(+-)} + m_{pion(o)}) = 0.5083856, \qquad (9)$$

$$1 - y = m_{pion(o)} / (m_{pion(+-)} + m_{pion(o)}) = 0.4916144. \qquad (10)$$

There is a probability that the x neutron is composed of H^+ and $W_{(-),d=1}$ and a probability that $1\text{-}x$ is composed of H^o, resting neutral pion and Z^o. The mass of the last particle is $m_{Z(o)} = m_{W(o),d=1} - m_{pion(o)}$. The probabilities are as follows

$$x = m_{pion(o)} / m_{W(-),d=1} = 0.6255371, \qquad (11)$$

$$1 - x = 0.3744629. \qquad (12)$$

2. Calculations

The relative magnetic moments are equal to the ratio of the mass of proton (mass is 938.272 MeV [1A]) to mass of a charged component.

For the charged core of baryons H^+ (mass is 727.44 MeV [1A]) we obtain

$X = +938.27 / 727.44 = +1.28983$.

For $W_{(+-),d=1}$ (mass is 215.760 MeV [1A]) is

$Y_{+-} = \pm 938.27 / 215.760 = \pm 4.34868$.

For $W_{(-),k=0,d=2}$ (mass is 181.704 MeV [1A]) is

$Z_1 = -938.27 / 181.704 = -5.16374$.

For $W_{(-),k=1,d=2}$ (mass is $181.704 + 1 \cdot 25.213 = 206.917$ MeV – see formula (8)) is

$Z_2 = -938.27 / 206.917 = -4.53453$.

For $W_{(-),k=2,d=2}$ (mass is $181.704 + 3 \cdot 25.213 = 257.343$ MeV – see formula (8)) is

$Z_3 = -938.27 / 257.343 = -3.64600$.

For $W_{(+),k=2,d=2}$ is

$Z_4 = +938.27 / 257.343 = +3.64600$.

For $W_{(-),k=3,d=2}$ (mass is $181.704 + 7 \cdot 25.213 = 358.195$ MeV – see formula (8)) is

$Z_5 = -938.27 / 358.195 = -2.61944$.

Hyperon Λ

Composition of the hyperon Λ is (see Table 1)

$$\Lambda = n + W_{(o),k=0,d=2} = (\boldsymbol{A} + \boldsymbol{F} + L) / \boldsymbol{3} + (B + G + L) / 3 + (Be^{+} + Ge^{-} + L) / 3.$$

The Scale-Symmetric Theory shows that electric charge of electron is defined by torus composed of the Einstein-spacetime components [1A]. The mean radius of the torus is equal to $2/3$ of the reduced Compton radius of electron. This means that the electric radius of an electron interacting weakly with a baryon lies outside the baryon so the electric charge does not give a contribution to magnetic moment of the baryon. It is very difficult to localize the electric charge of electron because the torus is only specifically polarized the Einstein spacetime [1A]. This leads to conclusion that only the first component (precisely the A and F) gives contribution to the relative magnetic moment of hyperon Λ and it is the relative magnetic moment of neutron (the calculated value within SST is $R_{neutron} = -1.91343$ [1A]). Assume that probabilities for the all three components are the same so the relative magnetic moment R_{Λ} is

$$R_{\Lambda} = R_{neutron} / 3 \approx -0.64.$$

Table 1 *The relative magnetic moments of constituents of hyperons*

Constituent	Mass [MeV]	Relative magnetic moment Scale-Symmetric Theory
$A = H^{+}$	727.440	$X_o = +1.28983$
$B = H^{o}$	724.777	0
$Be^{+} = (H^{o} + e^{+}\nu_{e})$	727.440	does not concern
$e^{-} = e^{-}\nu_{e,anti}$	0.511	does not concern
$E = W_{(+),d=1}$	215.760	$Y_{+} = +4.34868$
$F = W_{(-),d=1}$	215.760	$Y_{-} = -4.34868$
$G = W_{(o),d=1}$	208.643	0
$Ge^{-} = (W_{(o),d=1} + e^{-}\nu_{e,anti})$	215.760	does not concern
$K = W_{(-),k=0,d=2}$	181.704	$Z_1 = -5.16374$
$L = W_{(o),k=0,d=2}$	175.709	0
$Le^{-} = (W_{(o),k=0,d=2} + e^{-}\nu_{e,anti})$	181.704	does not concern
$M = W_{(-),k=1,d=2}$	206.917	$Z_2 = -4.53453$
$P = W_{(o),k=1,d=2}$	200.922	0
$Pe^{-} = (W_{(o),k=1,d=2} + e^{-}\nu_{e,anti})$	206.917	does not concern
$S = W_{(-),k=2,d=2}$	257.343	$Z_3 = -3.64600$
$T = W_{(+),k=2,d=2}$	257.343	$Z_4 = +3.64600$
$U = W_{(o),k=2,d=2}$	251.348	0
$Ue^{-} = (W_{(o),k=2,d=2}.+ e^{-}\nu_{e,anti})$	257.343	does not concern
$Y = W_{(-),k=3,d=2}$	358.195	$Z_5 = -2.61944$
$Z = W_{(o),k=3,d=2}$	352.200	0
$Ze^{-} = (W_{(o),k=3,d=2}.+ e^{-}\nu_{e,anti})$	358.195	does not concern

In the third state of the hyperon Λ, the sum of the masses of H^{o} and $e^{+}\nu_{e}$ is equal to the mass of H^{+} whereas of $W_{(o),d=1}$ and $e^{-}\nu_{e,anti}$ is equal to the mass of $W_{(-),d=1}$. We can see that the mean mass of the hyperon Λ is 1115.649 MeV.

In each state of the hyperon Λ defined by the contents of a bracket (…), is only one pion W in the $d = 2$ state so the strangeness of the hyperon Λ is -1.

In each state of the hyperon Λ there is only the half-integral spin of the core of hyperons whereas there is lack of the unitary spins of the vector bosons E_W that appear in formula (8). This means that the spin of hyperon Λ is 1/2.

Hyperon Σ^+

Composition of the hyperon Σ^+ is

$$\Sigma^+ = \boldsymbol{y}\ (\boldsymbol{A} + G + U) + \boldsymbol{(1–y)}\ (B + G + \boldsymbol{T}).$$

The relative magnetic moment $R_{\Sigma(+)}$ is

$$R_{\Sigma(+)} = y\,X_o + (1 – y)\,Z_4 = +2.4482$$

whereas the mass is 1189.069 MeV.

In each state of the hyperon Σ^+ defined by the contents of a bracket (…), is only one pion W in the $d = 2$ state so the strangeness of the hyperon Σ^+ is –1.

The arrangement of spins in each state of the hyperon Σ^+ is as follows.

$$\uparrow \text{ and } \underbrace{\downarrow\uparrow + \downarrow}_{k = 2} \text{ spin} = 1/2$$

The smaller arrow denotes the half-integral spin of the core of hyperon whereas the larger arrows denote the unitary spins of the vector bosons E_W that appear in formula (8). The vector bosons E_W behave in the strong fields inside baryons as the electrons in the electromagnetic fields inside atoms. This leads to conclusion that the spins of the vector bosons are oriented in accordance with the Hund law. The spins of the core and the vector bosons E_W are oriented in such a way that the total angular momentum of a hyperon has minimal value but the spins of the vector bosons must be oriented in accordance with the Hund law. All of the relativistic pions are in the S state i.e. the azimuthal quantum numbers are equal to zero.

Hyperon Σ^o

Composition of the hyperon Σ^o is similar to hyperon Λ but instead the $W_{(o),k=0,d=2}$ there is the $W_{(o),k=2,d=2}$:

$$\Sigma^o = n + W_{(o),k=2,d=2} = (\boldsymbol{A} + \boldsymbol{F} + U) / \boldsymbol{3} + (B + G + U) / 3 + (Be^+ + Ge^- + U) / 3.$$

This difference does not change the relative magnetic moment so the relative magnetic moment $R_{\Sigma(o)}$ is

$$R_{\Sigma(o)} = R_\Lambda \approx –0.64$$

whereas the mass is 1191.288 MeV.

In each state of the hyperon Σ^o defined by the contents of a bracket (…), is only one pion W in the $d = 2$ state so the strangeness of the hyperon Σ^o is –1.

The arrangement of spins in each state of the hyperon Σ^o is as follows (the smaller arrow denotes the half-integral spin of the core of hyperon whereas the larger arrows the unitary spins of the vector bosons E_W that appear in formula (8)).

↑ and $\underbrace{\downarrow\uparrow}_{k\,=\,2}$ + ↓ spin = 1/2

Hyperon Σ^-

Composition of the hyperon Σ^- is

$$\Sigma^- = (\boldsymbol{A} + Ge^- + \boldsymbol{S})\,/\,\boldsymbol{2} + (Be^+ + G + e^- + Ue^-)\,/\,2.$$

The relative magnetic moment $R_{\Sigma(-)}$ is

$$R_{\Sigma(-)} = (X_o + Z_3)\,/\,2 = -1.1781$$

whereas the mass is 1197.240 MeV.

In each state of the hyperon Σ^- defined by the contents of a bracket (…), is only one pion W in the $d = 2$ state so the strangeness of the hyperon Σ^- is -1.

The arrangement of spins in each state of the hyperon Σ^- is as follows.

↑ and $\underbrace{\downarrow\uparrow}_{k\,=\,2}$ + ↓ spin = 1/2

The smaller arrow denotes the half-integral spin of the core of hyperons whereas the larger arrows the unitary spins of the vector bosons E_W that appear in formula (8).

Hyperon Ξ^o

There are the two states of neutron i.e. the charged (+,-) and uncharged (o,o). The uncharged state does not give a contribution to the mean relative magnetic moment (it is the mean magnetic moment in the nuclear magneton). Assume that probabilities of these two states for hyperons are the same so there appears the factor $f = 1/2$.

Composition of the hyperon Ξ^o is

$$\Xi^o = \{\boldsymbol{x}\,(\boldsymbol{A} + G + \boldsymbol{K} + P) + (1 - x)(Be^+ + G + Le^- + P)\}/\boldsymbol{2} + (B + G + L + P)/2.$$

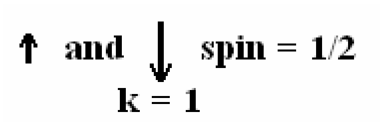
The relative magnetic moment $R_{\Xi(o)}$ is

$$R_{\Xi(o)} = x\;(X_o + Z_1)\,/\,2 = -1.2116$$

whereas the mass is 1314.380 MeV.

In each state of the hyperon Ξ^o defined by the contents of a bracket (…), are two pions W in the $d = 2$ state so the strangeness of the hyperon Ξ^o is -2.

The arrangement of spins in each state of the hyperon Ξ^o is as follows.



The smaller arrow denotes the half-integral spin of the core of hyperons whereas the larger arrows the unitary spins of the vector bosons E_W that appear in formula (8).

Hyperon Ξ^-

Composition of the hyperon Ξ^- is

$$\Xi^- = \{(\mathbf{1} - x)(\mathbf{A} + Ge^- + L + \mathbf{M}) + x\,(Be^+ + G + Le^- + Pe^-)\}/\mathbf{2} + (B + Ge^- + L + P)/2.$$

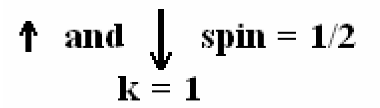
The relative magnetic moment $R_{\Xi(-)}$ is

$$R_{\Xi(-)} = (1 - x)\,(X_o + Z_2) / 2 = -0.6075$$

whereas the mass is 1321.146 MeV.

In each state of the hyperon Ξ^- defined by the contents of a bracket (…), are two pions W in the $d = 2$ state so the strangeness of the hyperon Ξ^- is –2.

The arrangement of spins in each state of the hyperon Ξ^- is as follows.



The smaller arrow denotes the half-integral spin of the core of hyperons whereas the larger arrows the unitary spins of the vector bosons E_W that appear in formula (8).

Hyperon Ω^-

Composition of the hyperon Ω^- is

$$\begin{aligned} \Omega^- &= \Xi^o + Y(\text{or } Ze^-) = \\ &= \{\mathbf{x}\,(\mathbf{A} + G + \mathbf{K} + P + \mathbf{Y}) + (1 - x)\,(Be^+ + G + Le^- + P + Ze^-)\} / \mathbf{2} + \\ &\quad + (B + G + L + P + Ze^-) / 2. \end{aligned}$$

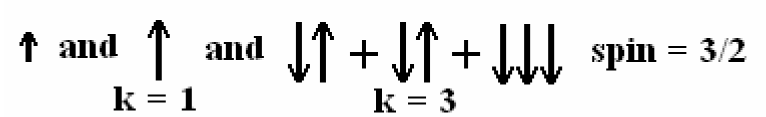
The relative magnetic moment $R_{\Omega(-)}$ is

$$R_{\Omega(-)} = x\,(X_o + Z_1 + Z_5) / 2 = -2.0309$$

whereas the mass is 1672.575 MeV.

In each state of the hyperon Ω^- defined by the contents of a bracket (…), are three pions W in the $d = 2$ state so the strangeness of the hyperon Ω^- is –3.

The arrangement of spins in each state of the hyperon Ω^- is as follows.



The smaller arrow denotes the half-integral spin of the core of hyperons whereas the larger arrows the unitary spins of the vector bosons E_W that appear in formula (8).

3. Summary

The Scale-Symmetric Theory (SST) is the lacking part of the Theory of Everything. SST describes the succeeding phase transitions of the non-gravitating Higgs field, the atom-like structure of baryons, and many other basic problems. Here, within SST, we calculated the magnetic moments and precise masses of hyperons, their spin and strangeness. Obtained results are consistent or very close to experimental data – they are collected in Tables 2-4.

Table 2 *Relative magnetic moments*

Nucleon or Hyperon	**Relative magnetic moment PDG [2]**	**Relative magnetic moment Scale-Symmetric Theory**
Proton p	+2.792847356(23)	+2.79360 [1A]
Neutron n	–1.9130427(5)	–1.91343 [1A]
Hyperon Λ	–0.613 ± 0.004	–0.64
Hyperon Σ^+	+2.458 ± 0.010	+2.4482
Hyperon Σ^o	?	–0.64
Hyperon Σ^-	–1.160 ± 0.025	–1.18
Hyperon Ξ^o	–1.250 ± 0.014	–1.21
Hyperon Ξ^-	–0.6507 ± 0.0025	–0.61
Hyperon Ω^-	–2.02 ± 0.05	–2.03

Table 3 *Rigorous mass of hyperons*

Particle	**Experimental mass PDG [2]**	**Rigorous theoretical mass Scale-Symmetric Theory**
Hyperon Λ	1115.683 ± 0.006	1115.649 MeV
Hyperon Σ^+	1189.37 ± 0.07	1189.069 MeV
Hyperon Σ^o	1192.642 ± 0.024	1191.288 MeV
Hyperon Σ^-	1197.449 ± 0.030	1197.240 MeV
Hyperon Ξ^o	1314.86 ± 0.20	1314.380 MeV
Hyperon Ξ^-	1321.71 ± 0.07	1321.146 MeV
Hyperon Ω^-	1672.45 ± 0.29	1672.575 MeV

Table 4 *Spin and strangeness of hyperons*

Particle	**Spin Scale-Symmetric Theory**	**Strangeness Scale-Symmetric Theory**
Hyperon Λ	1/2	–1
Hyperon Σ^+	1/2	–1
Hyperon Σ^o	1/2	–1
Hyperon Σ^-	1/2	–1
Hyperon Ξ^o	1/2	–2
Hyperon Ξ^-	1/2	–2
Hyperon Ω^-	3/2	–3

The lifetimes of the hyperons Ξ^o and Ξ^- are respectively $a = (2.90 \pm 0.09) \cdot 10^{-10}$ s and $b = (1.639 \pm 0.015) \cdot 10^{-10}$ s [2]. The ratio $a / (a + b)$ is close to the probability x so this probability should be associated with the relative magnetic moment of the hyperon Ξ^o whereas the ratio $b / (a + b)$ is close to $1–x$ so this probability should be associated with the relative magnetic moment of the hyperon Ξ^-. It is consistent with presented here the theory of hyperons.

The experimental data show that the hyperon Ω^- mostly decays into neutral hyperon Lambda and negatively charged kaon K^- (67.8 ± 0.07)% or neutral hyperon Ξ^o and negatively charged pion π^- (23.6 ± 0.07)% [2]. It suggests that there should dominate the structure of the hyperon Ω^- composed of the neutral hyperon Ξ^o and negatively charged relativistic pion π^-. It follows as well from the fact that the neutral hyperon Ξ^o is more stable (i.e. its lifetime is longer) than the negatively charged Ξ^-. It is consistent with presented here the theory of hyperons also.

Notice also that the percentages for the main channels of the decay of Λ and Σ^+ hyperons are close to the x, $1-x$, y, $1-y$ probabilities. This suggests that in a hyperon, before it decays, the $W_{(o),d=2}$ pion transits to the $d = 1$ state and during its decay the pion appears which was in the $d = 1$ state.

References

[1] Sylwester Kornowski (2015). *Scale-Symmetric Theory*
[1A]: http://vixra.org/abs/1511.0188 (Particle Physics)
[1B]: http://vixra.org/abs/1511.0223 (Cosmology)
[1C]: http://vixra.org/abs/1511.0284 (Chaos Theory)
[1D]: http://vixra.org/abs/1512.0020 (Reformulated QCD)
[2] K. Nakamura *et al.* (Particle Data Group), J. Phys. G **37**, 075021 (2010) and 2011 partial update for the 2012 edition.