The Neutrino Cross Sections in the Scale-Symmetric Theory

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Abstract: In the Standard Model (SM), neutrinos interact with quarks through charged current interactions (mediated by W bosons) and neutral current interactions (mediated by Z bosons). When we take into account the uncertainties then the measured in accelerator and the IceCube experiments cross-sections for neutrinos divided by their energy are consistent with the SM predictions. But there is still the proton spin crisis concerning the quarks and gluons so the SM assumptions for the neutrino-nucleon scattering are not clear. Here we calculated the ratios of cross section for neutrinos to neutrino energy using the Scale-Symmetric Theory (SST). According to SST, rotating neutrino produces a halo and disc (it looks as a miniature of active massive galaxy) both composed of the Einstein spacetime components which gravitate and are local i.e. are non-relativistic. The sum of masses of the neutrino halo and disc is equal to the neutrino energy. On the other hand, cross-section of neutrino is defined by radius of the disc which density is much higher than the neutrino halo. Below the threshold neutrino energy equal to 2.67 TeV, pions and other hadrons are not produced in the cost of neutrino energy (their production decreases both radii i.e. of the halo and disc) so the ratio of cross-section to neutrino energy is invariant. Above the threshold energy, more and more neutrino energy is consumed on the production of pions and heavier hadrons - it leads to a slower increase in cross section at higher energies in such a way that the ratio of cross section to neutrino energy decreases practically to zero for neutrino energy about 2,800 TeV (this is due to the scattering on heaviest atomic nuclei). The threshold energy for antineutrinos is two times higher than for neutrinos but the ratio of cross section to antineutrino energy for energies lower than the threshold energy is two times lower than for neutrinos - it follows from the internal helicities of nucleons, muons, neutrinos and antineutrinos. Obtained results are consistent with experimental data and we can verify presented here model because of the SST predictions.

1. Introduction

In the Standard Model (SM), neutrinos interact with quarks through charged current interactions (mediated by W bosons) and neutral current interactions (mediated by Z bosons). When we take into account the uncertainties then the measured in accelerator and the IceCube experiments cross-sections for neutrinos divided by their energy [1], [2], are consistent with the SM predictions [3]. But there is still the proton spin crisis concerning the quarks and gluons [4] so the SM assumptions for the neutrino-nucleon scattering are not clear.

Here we calculated the ratios of cross section for neutrinos to neutrino energy using the Scale-Symmetric Theory (SST) [5].

According to SST, rotating neutrino produces a disc-like halo and thin disc both composed of the Einstein spacetime (ES) components. It looks as a miniature of active massive galaxy – the rotating neutrino is an analogue to spinning "black hole" in centre of such galaxy, the disc is an analogue to the accretion disc around the "black hole", and the neutrino halo is an analogue to the galactic halo. Mechanisms of creation of such structure around rotating neutrino and spinning "black hole" are similar [6]. The ordered motions created in the surroundings of the central rotating object (generally, angular velocity and linear velocity of the object are parallel or antiparallel – for neutrinos this condition is always met) decrease pressure in plane perpendicular to the linear velocity. The pressure gradient causes that there is created the baryonic accretion disc of active galaxy or the neutrino disc which is the slightly compacted ES [5]. The baryons and/or the ES components inspiral towards the central object and are pushed along the axis of rotation – from them is created the halo.

Let us concentrate on the dynamics of the rotating neutrinos.

The ES components gravitate and are local [7] i.e. they are non-relativistic. An object can be relativistic (i.e. then their mass depends on velocity) only when there is a field composed of elements the object is built of. For example, proton is built of the ES components and there is the ES so proton is the relativistic particle [5]. On the other hand, the ES components are built of the entanglons [5] but there is not in existence a field composed of entanglons (entanglons can be exchanged only – they are responsible for the quantum entanglement) so the ES components are the non-relativistic objects – they are the local and gravitating objects but their mass does not depend on their velocity.

According to SST, there are in existence two meta-stable condensates composed of the ES components – it is the condensate in centre of muons and the condensate in centre of nucleons [5]. The muon and nucleon condensates are meta-stable because the ES components are moving on their surfaces on circular orbits with radii equal to the equatorial radii [5]. Density of the muon condensate is about $207 \approx m_{muon} / m_{electron}$ times higher than the nucleon condensate [5]. The neutrino disc consists of the much denser muon condensates so the area of circle defined by the neutrino disc is the cross section of rotating neutrino. On the other hand, the neutrino halo consists of the nucleon condensates. The sum of the masses of the neutrino disc and the neutrino halo, M, is equal to the energy of the neutrino (it is the rotational energy E) so there is obligatory the Einstein formula $E = Mc^2$.

In centre of electrons, there is an ES condensate also but it is very unstable [5]. The nucleon condensate, Y (here, the symbols denote both a particle and its mass), is the singlet state with total isospin 0 and the third component of isospin 0 so it is the isoscalar [5].

Rotating neutrino can be scattered on the ES condensates. Then there are exchanged the muon condensates between the neutrino disc and ES condensate so it is the weak interaction [5]. When the neutrino halo has sufficiently big radius, the nucleon condensates on surface of neutrino halo can transform into pions and other hadrons – here we will show that it is above the threshold neutrino energy equal to $E_{\nu,threshold} = 2{,}673$ GeV. Such transformation decreases both radii of the neutrino halo and neutrino disc i.e. measured cross section of neutrinos is lower than it follows from their energy. It leads to a slower increase in cross section for neutrinos carrying energy higher than $E_{\nu,threshold}$ in such a way that the ratio of cross section to energy of neutrino decreases practically to zero for neutrino energy about $2{,}800$ TeV – this is due to the scattering of neutrinos on heaviest atomic nuclei.

2. Scattering of neutrinos on isoscalar target

The condensate in nucleons has the radius equal to $R_{Condensate}$ = 0.871094·10^{-15} cm and mass Y = 424.124 MeV [5]. The condensate in muons has the radius equal to $R_{Con,muon}$ = 0.7354103·10^{-16} cm and mass $M_{Con,muon}$ ≈ 52.8 MeV [5].

The neutrino halo is a disc-like structure also but it thickness is about 11.8 times greater than the neutrino disc – it follows from the ratio of the diameters of the nucleon condensate and muon condensate. The constant ratio of diameters causes that below the threshold neutrino energy, the ratio of cross section to neutrino energy is an invariant.

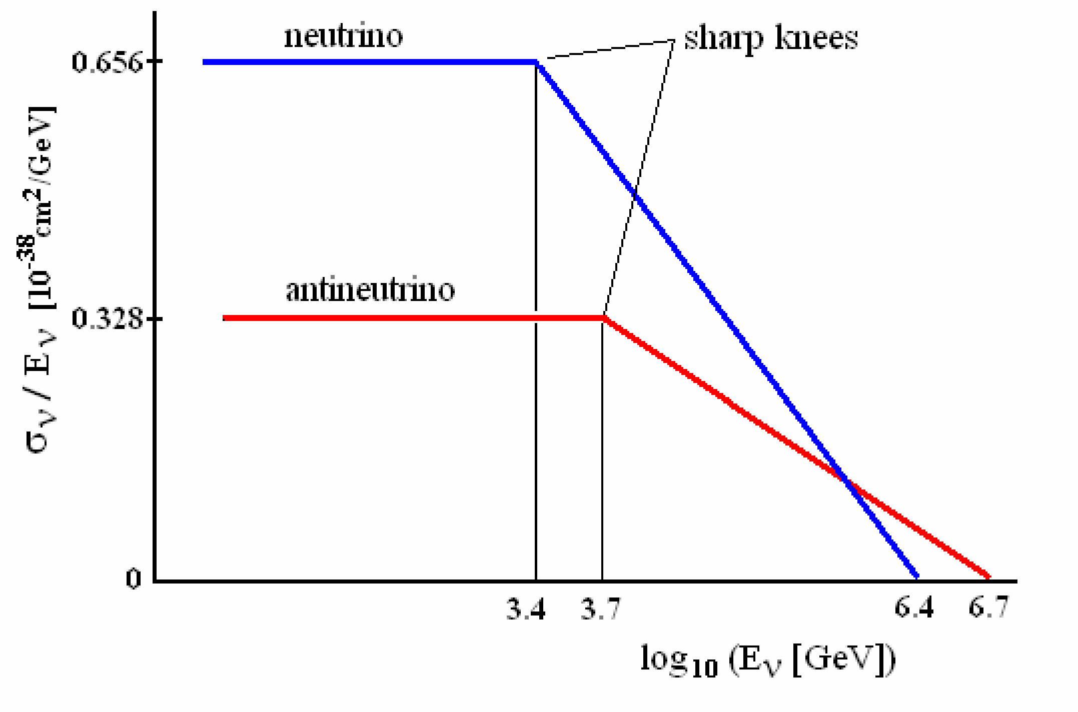
The disc-like neutrino halo is built of the nucleon condensates so the radius of the halo depends on the coupling constant for the weak interactions of the nucleon condensate which is $\alpha_{w(proton)}$ = 0.0187228615 [5]. On the other hand, the neutrino disc is built of the muon condensates so the radius of the disc depends on the coupling constant for the weak interactions of the muon condensate which is $\alpha_{w(electron-muon)}$ = 9.511082·10^{-7} [5]. The ratio of the coupling constants is

$$X_w = \alpha_{w(proton)} / \alpha_{w(electron-muon)} = 19{,}685.3. \quad (1)$$

SST shows that coupling constant for weak interactions is directly proportional to radius ([5]: see formula (76)).

These remarks lead to following formula for radius of the neutrino disc

$$R_{disc} = R_{halo} / X_w . \quad (2)$$



Neutrino cross section divided by neutrino energy for scattering of neutrinos on nucleons as a function of neutrino energy from the Scale-Symmetric Theory.

Neutrino carrying energy equal to mass of proton creates halo which radius is equal to the radius of the nucleon condensate $R_{Condensate}$. Cross section of neutrino, σ_ν, is equal to area of circle defined by the neutrino disc. Neutrino carrying energy equal to the rest mass of proton should have cross section, $\sigma_{v,p}$, equal to

$$\sigma_{v,p} = \pi\ (R_{Condensate} / X_w)^{2} = 0.61517 \cdot 10^{-38}\ \text{cm}^2. \tag{3}$$

Since $E_v = M_{proton}$, we obtain that the ratio of cross section to neutrino energy is

$$(\sigma_v / E_v)_{invariant} = \sigma_{v,p} / M_{proton} = 0.6556 \cdot 10^{-38}\ \text{cm}^2/\text{GeV} \approx 0.656 \cdot 10^{-38}\ \text{cm}^2/\text{GeV}. \tag{4}$$

The nucleon condensate is the zero-spin and zero-charge object and we can see that its mass is about 4 times greater than the rest mass of muon. It leads to conclusion that Y can decay to the 8 muon condensates or 4 muons

$$Y \rightarrow 8\ M_{Con,muon} \rightarrow 4\ (\mu^- + e^{+}*), \tag{5}$$

where $e^{+}*$ denotes virtual positron. In the beta decay of neutron, there appears electron which has the same internal helicity as the negatively charged muon [5]. It means that probability of appearance of negatively charged muon is much higher than of positively charged one. On the other hand, in the condensate of muon, there are two energetic neutrinos i.e. electron-antineutrino, $v_{e,anti}$, and muon-neutrino, v_μ, which appear in the muon decay [5]. When incoming neutrino is the muon-antineutrino then due to the weak interactions and opposite weak charges, initially there is created the $v_{\mu,anti}\ v_\mu$ pair. It means that energy of each component of the pair is $E_{v,anti}/2$, where $E_{v,anti}$ is the energy of incoming antineutrino. Next, the pair decays so the muon-antineutrino carries energy two times lower than the initial antineutrino. Below the threshold energy for neutrinos, cross section of neutrino is directly proportional to its energy so the ratio of cross section to the initial energy of neutrino is for antineutrinos two times lower. Notice as well that presented here model leads to the threshold energy for antineutrinos two times higher than for neutrinos. The two times higher threshold energy and the two times lower initial ratio of cross section to neutrino energy for antineutrinos follows from the internal helicities of nucleons, muons, neutrinos and antineutrinos.

For energies below the threshold energy, for muon-antineutrino we have

$$\sigma_{v,anti} / E_{v,anti} = (\sigma_v / 2) / E_{v,anti} = 0.328 \cdot 10^{-38}\ \text{cm}^2 / \text{GeV}\ . \tag{6}$$

According to SST, pions are the binary systems of loops with radius $R_{loop,pion} = 0.4649617 \cdot 10^{-13}$ cm [5]. When the neutrino halo has radius greater than $R_{loop,pion}$ then in the cost of neutrino energy there are produced the pions and other hadrons. It causes that the increases in radius of the neutrino discs (i.e. increases in the neutrino cross section) are smaller i.e. the ratio of cross section to neutrino energy decreases. Let us calculate the threshold energy for neutrinos when there are produced the hadrons

$$E_{v,threshold} = \pi\ (R_{Loop,pion} / X_w)^{2} / (\sigma_v / E_v)_{invariant} = 2{,}673\ \text{GeV}\ . \tag{7a}$$

$$log_{10}\ (E_{v,threshold}\ [\text{GeV}]) = 3.427 \approx 3.4\ . \tag{7b}$$

We can assume that when radius of neutrino halo is equal to radii of the heaviest atomic nuclei, i.e. $R_{nucleus} \approx 1.5\cdot10^{-12}$ cm, then cross section of neutrino is reduced practically to zero. It is for following neutrino energy

$$E_{\nu,end} = \pi\,(R_{nucleus} / X_w)^{\,2} / (\sigma_\nu / E_\nu)_{invariant} \approx 2{,}800{,}000 \text{ GeV} . \tag{8a}$$

$$log_{10}\,(E_{\nu,end}\,[\text{GeV}]) \approx 6.4 . \tag{8b}$$

For antineutrinos we obtain ($E_{\nu,anti,threshold} = 2\,E_{\nu,threshold}$ and $E_{\nu,anti,end} = 2\,E_{\nu,end}$)

$$log_{10}\,(E_{\nu,anti,threshold}\,[\text{GeV}]) \approx 3.7 . \tag{9}$$

$$log_{10}\,(E_{\nu,anti,end}\,[\text{GeV}]) \approx 6.7 . \tag{10}$$

Obtained here theoretical results are consistent with experimental data [1], [2].

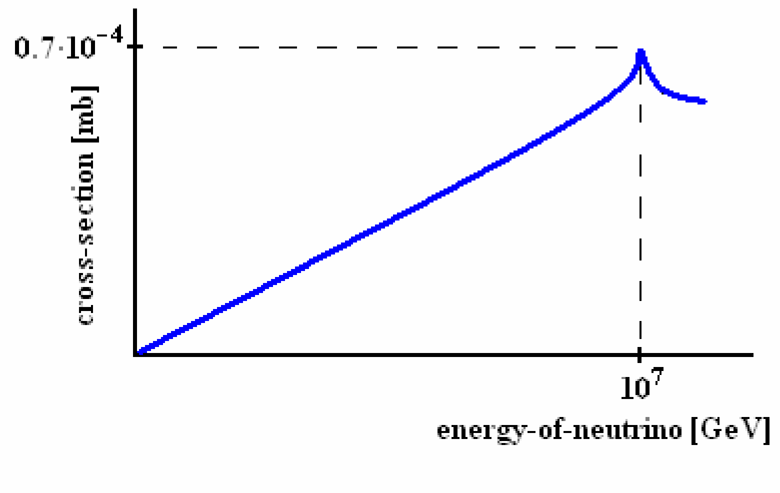
Notice that below the threshold energy, the ratio of mass of the neutrino disc to mass of the neutrino halo is

$$M_{disc} / M_{halo} = (M_{proton} - Y) / Y = 1.212 . \tag{11}$$

3. Scattering of neutrinos on electrons

The condensate in the centre of electron, which is responsible for the weak interactions, has radius $r_{p,electron} = 0.7354103\cdot10^{-16}$ cm and the same mass density as the condensate in the centre of nucleons [5]. Generally, due to the four-object symmetry [5], new electrons are produced as quadrupoles i.e. as two electron-positron pairs. Cross section for weak interactions of such object is

$$\sigma_{W,2(e+e-)} = 4\,\pi\,r_{p,electron}^{\;2} = 0.68\cdot10^{-31}\text{ cm}^2 \approx 0.7\cdot10^{-4}\text{ mb} . \tag{12}$$



Scattering of neutrinos on electrons.

Cross section for neutrinos scattered on electron quadrupoles as a function of neutrino energy should have maximum for neutrinos which area of circle defined by neutrino disc created by rotating neutrino is $\sigma_{\nu,max} = \sigma_{W,2(e+e-)} = 0.68\cdot10^{-31}$ cm^2 (it is not radius of neutrino halo). Mass density of the electron and nucleon condensates is the same so the weak interactions of neutrinos with electrons and neutrinos with nucleons should look the same. It means that we can calculate energy of neutrinos for the maximum cross section applying following formula

$$E_\nu = \sigma_{\nu,max} / (\sigma_\nu / E_\nu)_{\text{invariant}} = 1.0 \cdot 10^7 \text{ GeV} . \quad (13)$$

Obtained here results are consistent with experimental data [8].

4. Summary

Within the Scale-Symmetric Theory we showed that in the curve σ_ν/E_ν [cm^2/GeV] = $f\{log_{10}(E_\nu$ [GeV]$)\}$ for neutrinos and antineutrinos there appear the characteristic elements that are not observed in the Standard-Model curves i.e. SST leads to the sharp knees for the threshold neutrino energy equal to 2.673 TeV ($\log_{10}$(2673 [GeV]) = 3.427 ≈ 3.4) and for two times higher threshold energy of antineutrinos ($\log_{10}$(5346 [GeV]) = 3.728 ≈ 3.7) and leads to the ratio of cross section to neutrino energy practically equal to zero for neutrino energy about 2,800 TeV (this is due to the scattering on heaviest atomic nuclei) i.e. $\log_{10}$(2,800,000 [GeV]) ≈ 6.4 (for antineutrino is $\log_{10}$(5,600,000 [GeV]) ≈ 6.7). Contrary to the SST curves, the SM curves are smooth and for the threshold energy for neutrinos SM gives about 0.58 cm^2/GeV, i.e. it is about 12% lower value than it follows from SST which gives about 0.66 cm^2/GeV.

The future more precise experiments will show whether there are the sharp knees and the ends of the curves for strictly determined energy of neutrinos/antineutrinos. Possible confirmation of predictions will give credence to the Scale-Symmetric Theory.

Most important in the Scale-Symmetric Theory of the neutrino-nucleon/electron scattering are the meta-stable/unstable Einstein-spacetime condensates. SST shows that detection of the nucleon condensates and the electron condensates is extremely difficult because they look as the ES (i.e. the ES components are loosely packed i.e. they are not entangled) with a little higher mass density (1 part in 40,363 parts [5]) – we can detect groups of them indirectly via gravitational lensing but such effect is very weak. Emphasize that the ES condensates are not the dark-matter structures responsible for the non-Newtonian rotation of spiral galaxies [9]. It is easier to detect the muon condensates (1 part in 195 parts [5]) so we can detect them indirectly measuring the cross sections of neutrinos – of course, it is an indirect detection.

Notice that in presented here model, there are no free parameters. Number of initial conditions applied in SST is much smaller than in SM.

References

[1] K. A. Olive *et al.* [Particle Data Group Collaboration]. “Review of Particle Physics” Chin. Phys. C **38**, 090001 (2014)

[2] The IceCube Collaboration (published online: 22 November 2017). “Measurement of the multi-TeV neutrino interaction cross-section with IceCube using Earth absorption” *Nature* **551**, 596-600 (30 November 2017)
doi:10.1038/nature24459
arXiv:1711.08119v1 [hep-ex] 22 Nov 2017

[3] A. Cooper-Sarkar, P. Mertsch and S. Sarkar (2011). “The high energy neutrino cross-section in the Standard Model and its uncertainty”
JHEP **1108**, 042 (2011)

[4] Brookhaven National Laboratory
"Physicists narrow search for solution to proton spin puzzle."
ScienceDaily (4 November 2014)
<www.sciencedaily.com/releases/2014/11/141104111150.htm>
[5] Sylwester Kornowski (6 June 2016). "Foundations of the Scale-Symmetric Physics (Main Article No 1: Particle Physics)"
http://vixra.org/abs/1511.0188
[6] Sylwester Kornowski (2016). "The Revised Theory of Black Holes and Accretion Discs"
http://vixra.org/abs/1508.0215
[7] Sylwester Kornowski (15 November 2017). "Two-Component Spacetime as a Mixture of Non-Locality and Locality: A Conceptual Error about Gravitational Waves, the Different Theories of Gravitation and the Matter-Antimatter Asymmetry"
http://vixra.org/abs/1711.0324
[8] Joseph A. Formaggio, G. P. Zeller (31 May 2013). "From eV to EeV: Neutrino Cross-Sections Across Energy Scales"
arXiv:1305.7513v1 [hep-ex]
[9] Sylwester Kornowski (18 June 2016). "The Dark-Matter Mechanism and Orbital Speeds of Stars in Galaxies"
http://vixra.org/abs/1410.0031