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6d Dirac fermion on a rectangle; scrutinizing boundary conditions, mode functions and spectrum. (English) Zbl 1373.81199

Nucl. Phys., B 922, 186-225 (2017).

Summary: We classify possible boundary conditions of a 6d Dirac fermion Ψ on a rectangle under the requirement that the 4d Lorentz structure is maintained, and derive the profiles and spectrum of the zero modes and nonzero KK modes under the two specific boundary conditions, (i) 4d-chirality positive components being zero at the boundaries and (ii) internal chirality positive components being zero at the boundaries. In the case of (i), twofold degenerated chiral zero modes appear which are localized towards specific directions of the rectangle pointed by an angle parameter θ. This leads to an implication for a new direction of pursuing the origin of three generations in the matter fields of the standard model, even though triple-degenerated zero modes are not realized in the six dimensions. When such 6d fermions couple with a 6d scalar with a vacuum expectation value, θ contributes to a mass matrix of zero-mode fermions consisting of Yukawa interactions. The emergence of the angle parameter θ originates from a rotational symmetry in the degenerated chiral zero modes on the rectangle extra dimensions since they do not feel the boundaries. In the case of (ii), this rotational symmetry is promoted to the two-dimensional conformal symmetry though no chiral massless zero mode appears. We also discuss the correspondence between our model on a rectangle and orbifold models in some details.

MSC:

81Q05	Closed and approximate solutions to the Schrödinger, Dirac, Klein-Gordon and other equations of quantum mechanics	Cited in **1** Document
81V22	Unified quantum theories	
83E15	Kaluza-Klein and other higher-dimensional theories	
35P05	General topics in linear spectral theory for PDEs	
35F15	Boundary value problems for linear first-order PDEs	
81R05	Finite-dimensional groups and algebras motivated by physics and their representations	
57R18	Topology and geometry of orbifolds	

Full Text: DOI arXiv

References:

[1] Arkani-Hamed, N.; Dimopoulos, S.; Dvali, G. R., The hierarchy problem and new dimensions at a millimeter, Phys. Lett. B, 429, 263-272, (1998) · Zbl 1355.81103

[2] Antoniadis, I.; Arkani-Hamed, N.; Dimopoulos, S.; Dvali, G. R., New dimensions at a millimeter to a Fermi and superstrings at a TeV, Phys. Lett. B, 436, 257-263, (1998)

[3] Gogberashvili, M., Hierarchy problem in the shell universe model, Int. J. Mod. Phys. D, 11, 1635-1638, (2002)

[4] Randall, L.; Sundrum, R., A large mass hierarchy from a small extra dimension, Phys. Rev. Lett., 83, 3370-3373, (1999) · Zbl 0946.81063

[5] Hatanaka, H.; Inami, T.; Lim, C. S., The gauge hierarchy problem and higher dimensional gauge theories, Mod. Phys. Lett. A, 13, 2601-2612, (1998)

[6] Csaki, C.; Grojean, C.; Murayama, H.; Pilo, L.; Terning, J., Gauge theories on an interval: unitarity without a Higgs, Phys. Rev. D, 69, (2004)

[7] Csaki, C.; Grojean, C.; Hubisz, J.; Shirman, Y.; Terning, J., Fermions on an interval: quark and lepton masses without a Higgs, Phys. Rev. D, 70, (2004)

[8] Csaki, C.; Hubisz, J.; Meade, P., TASI lectures on electroweak symmetry breaking from extra dimensions, (Physics in D ⊠ 4. Proceedings, Theoretical Advanced Study Institute in Elementary Particle Physics, TASI 2004, Boulder, USA, June 6-July 2, 2004, (2005)), 703-776

[9] Kawamura, Y., Gauge symmetry breaking from extra space S^1 / Z_2, Prog. Theor. Phys., 103, 613-619, (2000)

[10] Kawamura, Y., Triplet doublet splitting, proton stability and extra dimension, Prog. Theor. Phys., 105, 999-1006, (2001)

[11] Hall, L. J.; Nomura, Y., Gauge unification in higher dimensions, Phys. Rev. D, 64, (2001)

[12] Hebecker, A.; March-Russell, J., The structure of GUT breaking by orbifolding, Nucl. Phys. B, 625, 128-150, (2002) · Zbl 0985.81132

[13] Fujimoto, Y.; Nagasawa, T.; Ohya, S.; Sakamoto, M., Phase structure of gauge theories on an interval, Prog. Theor. Phys., 126, 841-854, (2011) · Zbl 1242.81110

[14] Kaplan, D. E.; Tait, T. M.P., New tools for fermion masses from extra dimensions, JHEP, 11, (2001)

[15] Fujimoto, Y.; Nagasawa, T.; Nishiwaki, K.; Sakamoto, M., Quark mass hierarchy and mixing via geometry of extra dimension with point interactions, PTEP, 2013, (2013)

[16] Fujimoto, Y.; Nishiwaki, K.; Sakamoto, M., CP phase from twisted Higgs vacuum expectation value in extra dimension, Phys. Rev. D, 88, 11, (2013)

[17] Fujimoto, Y.; Nishiwaki, K.; Sakamoto, M.; Takahashi, R., Realization of lepton masses and mixing angles from point interactions in an extra dimension, JHEP, 10, (2014)

[18] Cai, C.; Zhang, H.-H., Majorana neutrinos with point interactions, Phys. Rev. D, 93, 3, (2016)

[19] Libanov, M. V.; Troitsky, S. V., Three fermionic generations on a topological defect in extra dimensions, Nucl. Phys. B, 599, 319-333, (2001) · Zbl 1097.81931

[20] Frere, J. M.; Libanov, M. V.; Troitsky, S. V., Three generations on a local vortex in extra dimensions, Phys. Lett. B, 512, 169-173, (2001) · Zbl 0969.81656

[21] Frere, J. M.; Libanov, M. V.; Troitsky, S. V., Neutrino masses with a single generation in the bulk, JHEP, 11, (2001) · Zbl 0969.81656

[22] Frere, J. M.; Moreau, G.; Nezri, E., Neutrino mass patterns within the seesaw model from multilocalization along extra dimensions, Phys. Rev. D, 69, (2004)

[23] Cremades, D.; Ibanez, L. E.; Marchesano, F., Computing Yukawa couplings from magnetized extra dimensions, JHEP, 05, (2004)

[24] Abe, H.; Kobayashi, T.; Ohki, H., Magnetized orbifold models, JHEP, 09, (2008) · Zbl 1245.81254

[25] Abe, H.; Choi, K.-S.; Kobayashi, T.; Ohki, H., Three generation magnetized orbifold models, Nucl. Phys. B, 814, 265-292, (2009) · Zbl 1194.81248

[26] Fujimoto, Y.; Kobayashi, T.; Miura, T.; Nishiwaki, K.; Sakamoto, M., Shifted orbifold models with magnetic flux, Phys. Rev. D, 87, 8, (2013)

[27] Abe, T.-H.; Fujimoto, Y.; Kobayashi, T.; Miura, T.; Nishiwaki, K.; Sakamoto, M., Z_N twisted orbifold models with magnetic flux, JHEP, 01, (2014)

[28] Abe, T.-h.; Fujimoto, Y.; Kobayashi, T.; Miura, T.; Nishiwaki, K.; Sakamoto, M., Operator analysis of physical states on magnetized T^2 / Z_N orbifolds, Nucl. Phys. B, 890, 442-480, (2014) · Zbl 1326.81255

[29] Abe, T.-h.; Fujimoto, Y.; Kobayashi, T.; Miura, T.; Nishiwaki, K.; Sakamoto, M.; Tatsuta, Y., Classification of three-generation models on magnetized orbifolds, Nucl. Phys. B, 894, 374-406, (2015) · Zbl 1328.81219

[30] Matsumoto, Y.; Sakamura, Y., Yukawa couplings in 6D gauge Higgs unification on T^2 / Z_N with magnetic fluxes, PTEP, 2016, 5, (2016) · Zbl 1361.81166

[31] Fujimoto, Y.; Kobayashi, T.; Nishiwaki, K.; Sakamoto, M.; Tatsuta, Y., Comprehensive analysis of Yukawa hierarchies on T^2 / Z_N with magnetic fluxes

[32] Horvath, Z.; Palla, L.; Cremmer, E.; Scherk, J., Grand unified schemes and spontaneous compactification, Nucl. Phys. B, 127, 57-65, (1977)

[33] Randjbar-Daemi, S.; Salam, A.; Strathdee, J. A., Spontaneous compactification in six-dimensional Einstein-Maxwell theory, Nucl. Phys. B, 214, 491-512, (1983)

[34] Dohi, H.; Kakuda, T.; Nishiwaki, K.; Oda, K.-y.; Okuda, N., Notes on sphere-based universal extra dimensions, Afr. Rev. Phys., 9, (2014)

[35] Neronov, A., Fermion masses and quantum numbers from extra dimensions, Phys. Rev. D, 65, (2002)

[36] Parameswaran, S. L.; Randjbar-Daemi, S.; Salvio, A., Gauge fields, fermions and mass gaps in 6D brane worlds, Nucl. Phys. B, 767, 54-81, (2007) · Zbl 1117.83381

[37] Gogberashvili, M.; Midodashvili, P.; Singleton, D., Fermion generations from 'apple-shaped' extra dimensions, JHEP, 08, (2007) · Zbl 1326.81150

[38] Kehagias, A.; Tamvakis, K., Box compactification and supersymmetry breaking, Phys. Lett. B, 603, 249-256, (2004) · Zbl 1247.81205

[39] Tran, N.-K., Tracking gauge symmetry breaking on intervals: 5-dim flat space-time, Nucl. Phys. B, 734, 246-271, (2006)

[40] Nilse, L., Classification of 1D and 2D orbifolds, AIP Conf. Proc., 903, 411-414, (2007)

[41] Cacciapaglia, G.; Csaki, C.; Grojean, C.; Terning, J., Field theory on multi-throat backgrounds, Phys. Rev. D, 74, (2006)

[42] Cacciapaglia, G.; Deandrea, A.; Deutschmann, N., Dark matter and localised fermions from spherical orbifolds?, JHEP, 04, (2016) · Zbl 1388.83520

[43] Andriot, D.; Cacciapaglia, G.; Deandrea, A.; Deutschmann, N.; Tsimpis, D., Towards Kaluza-Klein dark matter on nilmanifolds, JHEP, 06, (2016) · Zbl 1390.83306

[44] Appelquist, T.; Cheng, H.-C.; Dobrescu, B. A., Bounds on universal extra dimensions, Phys. Rev. D, 64, (2001)

[45] Dobrescu, B. A.; Ponton, E., Chiral compactification on a square, JHEP, 03, (2004)

[46] Burdman, G.; Dobrescu, B. A.; Ponton, E., Six-dimensional gauge theory on the chiral square, JHEP, 02, (2006)

[47] Maru, N.; Nomura, T.; Sato, J.; Yamanaka, M., The universal extra dimensional model with S^2 / Z_2 extra-space, Nucl. Phys. B, 830, 414-433, (2010) · Zbl 1203.83070

[48] Cacciapaglia, G.; Deandrea, A.; Llodra-Perez, J., A dark matter candidate from Lorentz invariance in 6D, JHEP, 03, (2010) · Zbl 1271.83083

[49] Dohi, H.; Oda, K.-y., Universal extra dimensions on real projective plane, Phys. Lett. B, 692, 114-120, (2010)

[50] Cheng, H.-C.; Matchev, K. T.; Schmaltz, M., Radiative corrections to Kaluza-Klein masses, Phys. Rev. D, 66, (2002)

[51] Da Rold, L., Radiative corrections in 5-D and 6-D expanding in winding modes, Phys. Rev. D, 69, (2004)

[52] Ponton, E.; Wang, L., Radiative effects on the chiral square, JHEP, 11, (2006)

[53] Cacciapaglia, G.; Deandrea, A.; Llodra-Perez, J., The universal real projective plane: LHC phenomenology at one loop, JHEP, 10, (2011) · Zbl 1303.81105

[54] Maru, N.; Nomura, T.; Sato, J., One-loop radiative correction to Kaluza-Klein masses in S^2 / Z_2 universal extra-dimensional model, PTEP, 2014, 8, (2014) · Zbl 1331.83098

[55] Dobrescu, B. A.; Poppitz, E., Number of fermion generations derived from anomaly cancellation, Phys. Rev. Lett., 87, (2001)

[56] Arkani-Hamed, N.; Cohen, A. G.; Georgi, H., Anomalies on orbifolds, Phys. Lett. B, 516, 395-402, (2001) · Zbl 0971.81153

[57] Borghini, N.; Gouverneur, Y.; Tytgat, M. H.G., Anomalies and fermion content of grand unified theories in extra dimensions, Phys. Rev. D, 65, (2002)

[58] Asaka, T.; Buchmuller, W.; Covi, L., Bulk and brane anomalies in six-dimensions, Nucl. Phys. B, 648, 231-253, (2003) · Zbl 1005.81044

[59] von Gersdorff, G.; Quiros, M., Localized anomalies in orbifold gauge theories, Phys. Rev. D, 68, (2003) · Zbl 1005.81053

[60] Scrucca, C. A.; Serone, M., Anomalies in field theories with extra dimensions, Int. J. Mod. Phys. A, 19, 2579-2642, (2004) · Zbl 1080.81066

[61] von Gersdorff, G., Anomalies on six dimensional orbifolds, JHEP, 03, (2007)

[62] Sakamoto, M.; Tachibana, M.; Takenaga, K., Spontaneously broken translational invariance of compactified space, Phys. Lett. B, 457, 33-38, (1999)

[63] Sakamoto, M.; Tachibana, M.; Takenaga, K., Spontaneous supersymmetry breaking from extra dimensions, Phys. Lett. B, 458, 231-236, (1999)

[64] Sakamoto, M.; Tachibana, M.; Takenaga, K., A new mechanism of spontaneous SUSY breaking, Prog. Theor. Phys., 104, 633-676, (2000)

[65] Ohnishi, K.; Sakamoto, M., Novel phase structure of twisted $O(N)$$\phi^4$ model on $M^{D - 1} \times S^1$, Phys. Lett. B, 486, 179-185, (2000) · Zbl 1050.81581

[66] Matsumoto, S.; Sakamoto, M.; Tanimura, S., Spontaneous breaking of the rotational symmetry induced by monopoles in extra dimensions, Phys. Lett. B, 518, 163-170, (2001) · Zbl 0971.81043

[67] Sakamoto, M.; Tanimura, S., Spontaneous breaking of the C, P, and rotational symmetries by topological defects in extra two dimensions, Phys. Rev. D, 65, (2002)

[68] Haba, N.; Oda, K.-y.; Takahashi, R., Top Yukawa deviation in extra dimension, Nucl. Phys. B, Nucl. Phys. B, 824, 331-128, (2010), Erratum: · Zbl 1196.81260

[69] Green, M. B.; Schwarz, J. H.; Witten, E., Superstring theory, (1987), Cambridge University Press

[70] Gabriel, S.; Nandi, S.; Seidl, G., 6D higgsless standard model, Phys. Lett. B, 603, 74, (2004)

[71] Fujimoto, Y.; Hasegawa, K.; Nishiwaki, K.; Sakamoto, M.; Tatsumi, K., Supersymmetry in 6d Dirac action

[72] Barbieri, R.; Contino, R.; Creminelli, P.; Rattazzi, R.; Scrucca, C. A., Anomalies, Fayet-Iliopoulos terms and the consistency of orbifold field theories, Phys. Rev. D, 66, (2002)

[73] Cooper, F.; Khare, A.; Sukhatme, U., Supersymmetry and quantum mechanics, Phys. Rep., 251, 267-385, (1995)

[74] Cheon, T.; Fulop, T.; Tsutsui, I., Symmetry, duality and anholonomy of point interactions in one-dimension, Ann. Phys., 294, 1-23, (2001) · Zbl 1016.81026

[75] Lim, C. S.; Nagasawa, T.; Sakamoto, M.; Sonoda, H., Supersymmetry in gauge theories with extra dimensions, Phys. Rev. D, 72, (2005)

[76] Lim, C. S.; Nagasawa, T.; Ohya, S.; Sakamoto, K.; Sakamoto, M., Supersymmetry in 5d gravity, Phys. Rev. D, 77, (2008)