Particles and Gravity I

1. Brief introduction to classical field theory:
   - Special relativity ([1] sec. 2)
   - The variational principle and the Lagrange formulation of a classical field theory
   - Electrodynamics and gauge invariance (gauge fixing) ([1] sec. 2)
   - The Klein-Gordon field
   - The Dirac field
   - Yang-Mills theories
   - The Noether's theorem for internal symmetries and space-time translations
   - The energy-momentum tensor for the electromagnetic, the Klein-Gordon and the Dirac field
2. Basics of quantum field theory:
   - Path integrals: from quantum mechanics to fields and particles, propagator for massive scalar and vector fields [2]
   - Attraction v.s. repulsion ([2] sec. 1.4-1.6):
     - classical potential for scalar-, vector-mediated interactions
     - propagator for massive spin 2 particle a la Veltman [2, 7] and the classical potential for an exchange of spin 2 quanta
3. Gravity as a field theory:
   - Gravity as a theory of spin 2 gravitons described by a symmetric second rank tensor, construction of the kinetic part of the Lagrangian ([3] sec. 3)
   - Field equations for massless gravitons, gauge invariance ([3] sec. 3) and the path quantization in the harmonic gauge
   - Propagator for massless gravitons ([2] sec.VIII.1)
   - The Lagrangian and the propagator for massive gravitons (the Fierz-Pauli model)
   - The deflection of light by massless and massive gravitons and the van Dam–Veltman–Zakharov discontinuity

4. The General Relativity
    - The principle of equivalence ([1] sec. 3.1-3.4)
    - The principle of general covariance ([1] sec. 4.1)
    - Curvilinear coordinates and the tensor analysis ([1] sec. 4.2-4.7, [4] sec. 83, 85)
    - The general covariance v.s. local gauge invariance ([1] sec. 4.10)
    - The curvature ([1] 6.1-6.2, 6.6, [4] sec. 91, 92)
    - The Einstein's field equations ([1] 7.1) and the Lagrangian formulation of the General Relativity ([1] sec. 12.1-12.4, [4] sec. 93, 95 and [9] appendix E1)
    - Conformal transformations and invariance of the Klein-Gordon and Maxwell equations ([9] appendix D)
5. Experimental tests of the General Relativity
    - The Newtonian gravity as a limit of the General Relativity ([1] sec. 3.4, 9.1, [4] sec. 96, [10] sec. 11.8)
    - Deflection of light ([1] sec. 8.5)
    - Short distance tests of the Newtonian gravity ([6])
6. Particles in a curved spacetime:
    - Effects of gravitation for a material particle and the electromagnetic field ([1] sec. 5.1-5.3)
    - The "minimal substitution rule", the Klein-Gordon field and the electromagnetic field in the General Relativity ([9] appendix E1, [3] sec. 10.2, 10.3, 16.1)
    - Fermions in a gravitational field

Literatura

[1] S. Weinberg, "Gravitation and cosmology : principles and applications of the general theory of relativity".

[2] A. Zee, "Quantum field theory in a nutshell".

[3] R. Feynman, F. Morinigo and W. Wagner, "Feynman Lectures on Gravitation".

[4] L. Landau and E. Lifshitz, "The Classical Theory of Fields".

[5] H. van Dam and M. J. G. Veltman, "Massive And Massless Yang-Mills And Gravitational Fields," Nucl. Phys. B **22**, 397 (1970); P. Van Nieuwenhuizen, "On Ghost-Free Tensor Lagrangians And Linearized Gravitation," Nucl. Phys. B **60**, 478 (1973); C. Deffayet, G. R. Dvali, G. Gabadadze and A. I. Vainshtein, "Nonperturbative continuity in graviton mass versus perturbative discontinuity," Phys. Rev. D **65**, 044026 (2002) [arXiv:hep-th/0106001].

[6] A. Kehagias and K. Sfetsos, "Deviations from the $1/r^2$ Newton law due to extra dimensions," Phys. Lett. B **472**, 39 (2000) [arXiv:hep-ph/9905417]; J. C. Long, H. W. Chan and J. C. Price, "Experimental status of gravitational-strength forces in the sub-centimeter regime," Nucl. Phys. B **539**, 23 (1999) [arXiv:hep-ph/9805217]; J. C. Long, H. W. Chan, A. B. Churnside, E. A. Gulbis, M. C. M. Varney and J. C. Price, "Upper limits to submillimeter-range forces from extra space-time dimensions," Nature **421**, 922 (2003).

[7] M. J. Veltman In: R. Bailin and J. Zinn-Justin, Editors, *Methods in Field Theory*, Proceedings of the 1975 Les Houches Summer School, North-Holland, Amsterdam (1976), p. 265.

[8] T. Han, J. D. Lykken and R. J. Zhang, "On Kaluza-Klein states from large extra dimensions," Phys. Rev. D **59**, 105006 (1999) [arXiv:hep-ph/9811350].

[9] R. Wald, "General relativity".

[10] P. Collins, A. Martin and E. Squires, "Particle physics and cosmology".

[11] J. F. Donoghue, "General relativity as an effective field theory: The leading quantum corrections," Phys. Rev. D **50**, 3874 (1994) [arXiv:gr-qc/9405057].

[12] D. Dicus and S. Willenbrock, "Angular momentum content of a virtual graviton," Phys. Lett. B **609**, 372 (2005) [arXiv:hep-ph/0409316].

Bohdan Grzadkowski *Zygmunt Lalak*