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Some Higher-Derivative Theories in Practical Terms

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Since the final decades of the last century it has become clear that quantum field theory (QFT) represents a major framework for describing fundamental nature phenomena. The generalization of this framework for models containing higher-order derivative terms, however an old subject, still poses itself as a challenging one with many open problems and subtleties. The relevance of higher-derivative models relies not just on abstract mathematical points, actually many modern approaches to quantum gravity allow for higher-order derivatives, besides its importance on the description of interacting models with room for more degrees of freedom. We present here a brief overview of some specific aspects of higher-derivative theories. Rather than entering on the fundamentals of important open issues such as unitarity, positiveness and causality, we focus instead on particular historical facts and pinpoint a few practical feasible issues present in recent published works. Starting from the 1950 well-known Pais-Uhlenbeck groundbreaking paper, we discuss the higher-derivative models of Bopp-Podolsky, Lee-Wick, Pais-Uhlenbeck oscillator and possible higher-order generalizations for the Klein-Gordon action. By performing a comparative analysis among those models, we show that it is possible to infer properties and behavior for ones from the others, in this way shedding some light in the whole higher-derivative problem in QFT. The fourth-order Pais-Uhlenbeck oscillator is perhaps the simplest instance of a nontrivial and relevant higher-order model. Defined in the realm of quantum mechanics, it comes from the quantization of a fourth-order classical oscillator system and already displays the mains characteristics of its more robust cousin models in QFT. The Boppy-Podolsky and Lee-Wick models describe higher-derivative theories with vector gauge fields. We discuss the gauge-fixing process for those models and show how clever gauge choices can lead to neat handy propagators which can considerably simplify perturbative calculations. Concerning higher-order generalizations for the Klein-Gordon equation, we discuss the classical solutions for a recently proposed natural action containing arbitrarily higher powers of the d'Alembertian operator acting on a scalar field. Along with the mentioned comparative analysis among those models, we also consider the interesting approach of reducing the order of the derivatives at the cost of introducing extra variables, weighing pros and cons, and provide a few arguments regarding their physical interpretation. To concretely illustrate the ideas, we discuss a reduced-order version for the Bopp-Podolsky model which has appeared recently in the literature, with both advantages of lower-order derivatives and sensible physical interpretation in terms of massive and massless propagating modes.

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