論文 / 著書情報
Article / Book Information

題目(和文)	
Title(English)	Theoretical Study on Compositeness in Hadron Physics
著者(和文)	YINZanpeng
Author(English)	Zanpeng Yin
出典(和文)	学位:博士(理学), 学位授与機関:東京工業大学, 報告番号:甲第12827号, 授与年月日:2024年9月20日, 学位の種別:課程博士, 審査員:慈道 大介,伊藤 克司,須山 輝明,西田 祐介,関澤 一之
Citation(English)	Degree:Doctor (Science), Conferring organization: Tokyo Institute of Technology, Report number:甲第12827号, Conferred date:2024/9/20, Degree Type:Course doctor, Examiner:,,,,
学位種別(和文)	博士論文
Category(English)	Doctoral Thesis
種別(和文)	論文要旨
Type(English)	Summary

（博士課程）
Doctoral Program

論 文 要 旨

THESIS SUMMARY

系・コース： Department of, Graduate major in	物理学 系 コース	申請学位（専攻分野）： Academic Degree Requested	博士 Doctor of （ 理学 ）
学生氏名： Student's Name	YIN Zanpeng	審査員主査： Chief Examiner	慈道大介

要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words ）

In this thesis, we attempt to study the consistency and evaluation of compositeness in hadron physics using a theoretical approach.

Hadrons are particles governed by the Quantum Chromodynamics (QCD) and are considered bound states of quarks and gluons. However, the full picture is much more complex than composing the particle like putting blocks together. Even though QCD can be calculated perturbatively, and quarks are asymptotically free at the high energy regime, non-perturbative effects are of great importance at the low energy regime where the hadron self-energy resides. It is caused by the increasing coupling constant of QCD at low energy, which also causes quark confinement. As a result, the hadron structure is much more complex than a bound state caused by other forces, like a hydrogen atom when viewed as a bound state of proton and electron bound state mediated by electromagnetic force, if the inner structure of proton is ignored.

Due to the complexity of low-energy QCD, the study of hadron physics usually works with effective models. For example, hadrons can be seen as constructed by constituent quarks in the quark model, where the mass of a hadron is just the addition of the mass of constituent quarks (different from the quarks in QCD, which is usually called bare quark to distinguish between them). In the quark model, we can categorize most of the hadrons into two categories: baryons that have three quarks and mesons that have two quarks, and they are the free states in the effective theory for hadrons. However, there are some hadrons, called exotic hadrons, that cannot be categorized as such.

Compositeness is a quantity proposed by S. Weinberg that attempts to distinguish if a particle is composed of other particles when such a particle manifests itself in a scattering process. This should be rather straightforward in a classical scenario but can face some difficulty in the Quantum Mechanics (QM) when there are several states existing at a similar energy scale, making these states can compete with each other in a Quantum Mechanical way. This is exactly the case in hadron physics, where quark pair creation, meson creation, and normal excitation are all on a similar energy scale. As a result, instead of a binary answer of yes or no, compositeness is defined as a proportion of the origin of a bound state that can be attributed to a scattering state. On the other hand, elementariness is defined as the proportion contributed by elementary states.

Even though it is suggested that deuteron is a composite particle of proton and neutron, which aligns with our understanding of nuclear physics, it yields an unrealistic negative quantity for elementariness when considering its probabilistic origin. This unrealistic quantity of elementariness (and compositeness) in the deuteron can be seen in many calculations yet we find there was no convincing solution or explanation. We will perform a theoretical study on this problem.

We first attempt to perform numerical calculations of the deuteron using a modern interpretation of compositeness with different models, in the hope of finding a type of interaction that can recover the deuteron properties and yield physical compositeness at the same time. We attempt low energy constants (LEC) models, one pion exchange potential (OPEP), Yamaguchi potential, and square well potential. However, none of the interactions can succeed in both deuteron property and physical compositeness. This raises the suspicion that the unphysical compositeness is caused by a deeper physical reason rather than the lack of a good interaction model.

We postulate that the unphysical compositeness is a consequence of attributing any energy

dependency into other states, and consequently compositeness, which we call the surjective interpretation. To test this postulation, we formalize a modified definition of compositeness with explicit energy dependency in interaction. Utilizing such a method, we are able to perform a perturbative calculation of compositeness and confirm our postulation. We conclude that an attractive perturbation from an energy-independent theory is highly likely to enhance the compositeness from unity, which is the case of deuteron. Our outcome indicates that, rather than the lack of a realistic interaction potential, it is the formalism of compositeness that requires modification.

The first proposed solution is to explicitly separate out different contributions from the interaction potential. In deuteron, the pions play an important role, and it may be counterintuitive to attribute such interaction to elementariness due to the lack of a one-body state. We propose a new quantity interactioness to account for this contribution, and finally combine interactionesss into compositeness considering its dynamical origin instead of the states. However, this proposed solution will destroy the pseudo-model-independent nature of the formalism of compositeness, diminishing its meaning in a phenomenology setting.

We then propose to define compositeness differently, which is motivated by the understanding of the deuteron and the original paper of Steven Weinberg. This new definition interprets energy decomposition as compositeness. An analytical calculation that has a connection with the original definition is discussed.