

Contents lists available at [ScienceDirect](http://www.sciencedirect.com)

Progress in Particle and Nuclear Physics

journal homepage: www.elsevier.com/locate/ppnp

Review

The QCD running coupling



Alexandre Deur^{a,*}, Stanley J. Brodsky^b, Guy F. de Téramond^c

^a Thomas Jefferson National Accelerator Facility, Newport News, VA 23606, USA

^b SLAC National Accelerator Laboratory, Stanford University, Stanford, CA 94309, USA

^c Universidad de Costa Rica, San José, Costa Rica

ARTICLE INFO

Article history:

Available online 9 May 2016

Keywords:

QCD
Coupling constant
Non-perturbative
Renormalization
Infrared properties
Hadron physics

ABSTRACT

We review the present theoretical and empirical knowledge for α_s , the fundamental coupling underlying the interactions of quarks and gluons in Quantum Chromodynamics (QCD). The dependence of $\alpha_s(Q^2)$ on momentum transfer Q encodes the underlying dynamics of hadron physics—from color confinement in the infrared domain to asymptotic freedom at short distances. We review constraints on $\alpha_s(Q^2)$ at high Q^2 , as predicted by perturbative QCD, and its analytic behavior at small Q^2 , based on models of nonperturbative dynamics. In the introductory part of this review, we explain the phenomenological meaning of the coupling, the reason for its running, and the challenges facing a complete understanding of its analytic behavior in the infrared domain. In the second, more technical, part of the review, we discuss the behavior of $\alpha_s(Q^2)$ in the high momentum transfer domain of QCD. We review how α_s is defined, including its renormalization scheme dependence, the definition of its renormalization scale, the utility of effective charges, as well as “Commensurate Scale Relations” which connect the various definitions of the QCD coupling without renormalization-scale ambiguity. We also report recent significant measurements and advanced theoretical analyses which have led to precise QCD predictions at high energy. As an example of an important optimization procedure, we discuss the “Principle of Maximum Conformality”, which enhances QCD’s predictive power by removing the dependence of the predictions for physical observables on the choice of theoretical conventions such as the renormalization scheme. In the last part of the review, we discuss the challenge of understanding the analytic behavior $\alpha_s(Q^2)$ in the low momentum transfer domain. We survey various theoretical models for the nonperturbative strongly coupled regime, such as the light-front holographic approach to QCD. This new framework predicts the form of the quark-confinement potential underlying hadron spectroscopy and dynamics, and it gives a remarkable connection between the perturbative QCD scale Λ and hadron masses. One can also identify a specific scale Q_0 which demarcates the division between perturbative and nonperturbative QCD. We also review other important methods for computing the QCD coupling, including lattice QCD, the Schwinger–Dyson equations and the Gribov–Zwanziger analysis. After describing these approaches and enumerating their conflicting predictions, we discuss the origin of these discrepancies and how to remedy them. Our aim is not only to review the advances in this difficult area, but also to suggest what could be an optimal definition of $\alpha_s(Q^2)$ in order to bring better unity to the subject.

© 2016 Elsevier B.V. All rights reserved.

* Corresponding author.

E-mail addresses: deurpam@jlab.org (A. Deur), sjbth@slac.stanford.edu (S.J. Brodsky), gdt@asterix.crnet.cr (G.F. de Téramond).

Contents

1.	Preamble	3
2.	Phenomenological overview: QCD and the behavior of α_s	3
3.	The strong coupling α_s in the perturbative domain	6
3.1.	Purpose of the running coupling	7
3.2.	The evolution of α_s in perturbative QCD	8
3.3.	Quark thresholds	10
3.4.	Computation of the pQCD effective coupling	11
3.5.	Renormalization group	13
3.6.	The Landau pole and the QCD parameter Λ	13
3.7.	Improvement of the perturbative series	14
3.7.1.	Effective charges and commensurate scale relations	14
3.7.2.	The Brodsky, Lepage and Mackenzie procedure and its extensions	15
3.7.3.	Principle of maximum conformality	16
3.8.	Other optimization procedures	17
3.9.	Determination of the strong coupling $\alpha_s(M_Z^2)$ or the QCD scale Λ	18
3.9.1.	Deep inelastic scattering	18
3.9.2.	Observables from e^+e^- collisions	19
3.9.3.	Observables from pp collisions	21
3.9.4.	Lattice QCD	21
3.9.5.	Heavy quarkonia	24
3.9.6.	Holographic QCD	24
3.9.7.	Pion decay constant	25
3.9.8.	Grand unification	25
3.9.9.	Comparison and discussion	25
4.	The strong coupling in the nonperturbative domain	25
4.1.	Effective charges	28
4.1.1.	Measurement of the effective charge from the Bjorken sum rule	29
4.1.2.	Measurement of the effective charge defined from e^+e^- annihilation	30
4.1.3.	Sudakov effective charges	31
4.2.	AdS/CFT and holographic QCD	32
4.3.	The effective potential approach	33
4.3.1.	The static $Q-\bar{Q}$ potential	33
4.3.2.	Constraints on the running coupling from the hadron spectrum	35
4.4.	The Schwinger–Dyson formalism	36
4.4.1.	The QCD coupling defined from Schwinger–Dyson equations	36
4.4.2.	Gauge choices	37
4.4.3.	Classes of solutions in the IR domain	37
4.4.4.	The massive gluon propagator	39
4.4.5.	The coupling defined from the ghost–gluon vertex	41
4.4.6.	Couplings defined from the 3-gluon and 4-gluon vertices	42
4.4.7.	Including quarks	43
4.4.8.	Gauge dependence	44
4.5.	Lattice gauge theory	44
4.5.1.	Lattice results for α_s in the IR	45
4.6.	Functional renormalization group equations	46
4.7.	The Gribov–Zwanziger approach	47
4.8.	Stochastic quantization	48
4.9.	Analytic and dispersive approaches	49
4.9.1.	Analytic approach	49
4.9.2.	Dispersive approach	51
4.10.	Background perturbation theory	52
4.11.	Optimized perturbation theory	52
4.12.	Quark-hadron duality	53
4.13.	The IR mapping of $\lambda\phi^4$ to Yang–Mills theories	53
4.14.	The Bogoliubov compensation principle	53
4.15.	Curci–Ferrari model	53
5.	Comparison and discussion	53
5.1.	Validity of the comparison	53
5.2.	Influence of the renormalization scheme	55
5.3.	The contributions of nonperturbative terms to $\alpha_s(Q^2)$	56
5.4.	Listing of the multiple IR-behavior found in the literature	59
6.	Conclusions	61
	Acknowledgments	63
	Appendix. Lexicon	63
	References	65

Download English Version:

<https://daneshyari.com/en/article/1853804>

Download Persian Version:

<https://daneshyari.com/article/1853804>

[Daneshyari.com](https://daneshyari.com)