

# Preface

The notion of quarks appeared in the early sixties just as a tool for the systematisation of the growing number of experimentally observed particles. First it was understood as a mathematical formulation of the SU(3) properties of hadrons, but soon it became clear that hadrons have to be considered as bound states of quarks (objects which we call now “constituent quarks”).

The next steps in understanding the quark–gluon structure of hadrons were made in the framework of Quantum Chromodynamics, a theory of coloured particles, as well as in the study of hard processes (*i.e.* in the study of hadron structure at small distances). We know that hadrons are, definitely, composed of large numbers of quarks, antiquarks and gluons. We have learned this from deep inelastic scattering experiments, and this picture is proven by many experiments on hard collisions and multiparticle production. At small distances quarks and gluons interact weakly, obeying the laws of QCD. An important fact is that a coloured quark or a gluon alone cannot leave the small region of the size of a hadron (*i.e.* that of the order of  $10^{-23}$  cm): they are confined — they can fly away only in groups which are colourless.

In the fifties and sixties of the last century virtually the whole physics of “elementary particles” (at that time also hadrons were considered as such) was devoted to the consideration of these distances. With the progress of experimental physics very soon even smaller distances were reached at which hard processes were investigated, giving a strong basis to Quantum Chromodynamics – a theory in the framework of which coloured particles can be considered perturbatively. This, and the hope that the key for understanding the physics of strongly interacting quarks and gluons was hidden just here, initiated research towards smaller and smaller distances, skipping the region of strong (soft) interactions.

We accumulated a very serious amount of knowledge on the hadron structure at extremely small distances. But looking back to the region of standard hadron sizes,  $10^{-24} - 10^{-23}$  cm, we realize now that, in fact, the physics at  $\sim 10^{-23}$  cm in its essential domains remains unknown [1, 2]. We left behind the hadron distances without really understanding all the observed phenomena. We have learned only a small part of what could be learned from the experimental results in that region, not to mention that experiments which could be easily carried out were also abandoned. The physics community just skipped some problems of strong interactions, partly of principal importance for understanding the processes near the confinement boundary. But at the time being one can see a disenchantment in running to the smallest possible distances (the highest possible energies). There are serious arguments in favour of returning to the region of strong interactions, to problems which were missed before. Moreover, these problems became an obstacle for having a complete picture of interactions provided us by QCD.

Considering the region of soft interactions, there are, naturally, different approaches based on rather different views. Let us list here some of them.

First of all, there are attempts to get all the needed answers on a strictly theoretical basis. Maybe new experiments are not necessary, for a great deal of experimental information has been accumulated, and scientists are equipped with the fundamental theory of quarks and gluons – QCD. So the only problem is how to handle wisely this knowledge. On the other hand, new experiments of a quite different type may be helpful: this could be the lattice calculations using the most powerful computers and the most sophisticated algorithms. Lattice calculations were and are a widely used approach; still, there are also controversial opinions.

First, one should take into account the fact that field theories, QCD included, and lattice QCD are defined in the four-dimensional space over sets of different cardinalities. In lattice calculations the space is modeled by a set of points in a four-dimensional space, with the aim to decrease the distance between the points up to zero ( $a \rightarrow 0$ , where  $a$  is the lattice spacing) and a simultaneous strong increase of the number of points. However, a set of numerous points (a lattice) is not equivalent to a continuous set used in field theories, thus there is no mathematically correct transition to QCD. Standard mathematics, *e.g.* the theory of fractals, give us many examples when characteristics constructed on a set of numerous points are different from those obtained for a continuum set (such examples, for instance, can be found in [3]).

Nevertheless, lattice calculations are quite promising, especially if they contain ingredients of observed phenomena. Such is, *e.g.*, the use of the quench approximation (the meson consists of two, the baryon of three quarks) in the calculation of non-exotic hadrons. Another example is the calculation of the mass of the tensor glueball. For many years lattice calculations predicted its mass about 2350 MeV. But recent experiments gave a mass of the order of 2000 MeV — and as soon as lattice calculations have included the requirement of linearity of the Regge trajectories (which is the experimental observation) the result for the glueball mass became 2000 MeV. Hence, the lattice QCD may be a rather useful tool for understanding the soft interaction region, provided it is supported by experimental results.

A quite radical way to change the object of our investigations would be to return to distances of the order of  $10^{-23}$  cm, both in experiment and theory. We know a lot about soft interactions, and this knowledge, the knowledge of the so-called quark model, though incomplete and amorphous, contains a large amount of information. Therefore the strategy, as we understand it, consists in a more fundamental study of the region  $\sim 10^{-23}$  cm based on the quark model and related experimental data.

In this book we present our views on the quark model, focusing on physics of hadrons. In this sense this book is a continuation of [2] where the main topics were soft hadron collisions at high energies.

Presenting the problems of hadron spectroscopy, we underline the statements having a solid background, and discuss the points which, though missed in previous studies, are needed for the restoration of soft interaction physics.

We focus our attention on methods of obtaining information about hadrons. The inconsistency of methods which we meet frequently leads to disagreement in the results and their interpretations. To illustrate this, a simple example is that in PDG [4] up to now there is no unique definition of the mass and the widths of a resonance, though the answer here is obvious: these characteristics are to be defined by the positions of amplitude poles in the invariant energy complex plane and the residues in these poles.

We tried to write the pieces devoted to technicalities of the treatment of data and the interpretation in the form of a brief set of prescriptions, *i.e.* as a handbook. Examples, explanations complemented by relevant calculations and available fitting results are given in the Appendices. In this book we do not aim to present a complete picture of the experimental situation but we would recommend recent surveys [5, 6].

By choosing the quark model as a basis for the study of soft physics,

we understand that we do not pursue far-reaching aims but try to solve immediate problems such as the systematics of meson and baryons, the determination of effective colour particles and their characteristics (we mean constituent quarks, effective massive gluons, diquarks and possible other formations). We mention here also a more ambiguous problem: the construction of effective theories in some ways similar to those used in condensed matter physics.

One of our main purposes is the determination of amplitude singularities responsible for the confinement of colour particles.

In the final chapter we tried to review the situation related to the quark model: to what extent the recent problems have been understood and what new tasks have been pushed forward. Also, in this discussion we touch possible far perspectives.

We are deeply indebted to our friends and colleagues who are no more with us.

Since the very beginning of our investigations, we had many discussions of the problems considered here with V.N. Gribov. He always showed vivid interest in the obtained results, and his comments helped us to achieve a deeper understanding of the related physics. It was him who underlined the fundamental interconnectedness between problems of hadron spectroscopy and confinement. The book is devoted to his memory.

Many results and methods presented in this book originated from the ideas formulated in the pioneering works made in collaboration with V.M. Shekhter.

Significant progress achieved in meson spectroscopy is related to the experiments initiated and completed under the leadership of Yu.D. Prokoshkin. His contribution provided much experimental information on which this book is based.

We are grateful to our colleagues D.V. Bugg, L.G. Dakhno, E. Klempt, M.N. Kobrinsky, V.N. Markov, D.I. Melikhov, V.A. Sadovnikova, U. Thoma, B.S. Zou who participated in investigations presented in this book. We would like to thank Ya.I. Azimov, G.S. Danilov, A. Frenkel, S.S. Gershtein, Gy. Kluge, Yu. Kalashnikova, A.K. Likhoded, L.N. Lipatov, M.G. Ryskin for helpful discussions and G.V. Stepanova for technical assistance. We thank RFBR, grant 07-02-01196-a for supporting the work. One of us (J.Ny.) is obliged to the OTKA grant No. 42671 for support.

A.V. Anisovich, V.V. Anisovich, M.A. Matveev,  
V.A. Nikonov, J. Nyiri, A.V. Sarantsev

## References

- [1] V.N. Gribov, *The Gribov Theory of Quark Confinement*, World Scientific, Singapore (2001)
- [2] V.V. Anisovich, M.N. Kobrinsky, J. Nyiri, Yu.M. Shabelski, *Quark Model and High Energy Collisions*, second edition, World Scientific, Singapore (2004).
- [3] B. Mandelbrot, *Fractals - a geometry of nature*, New Scientist (1990)
- [4] W.-M. Yao et al. (PDG), J. Phys. G: Nucl. Part. Phys. **33**, 1 (2006).
- [5] D.V. Bugg, Phys. Rept. **397**, 257 (2004).
- [6] E. Klempt, A. Zaitsev, Phys. Rept. **454**, 1 (2007).