Quarks in hadrons and nuclei

The idea of quarks as the ultimate constituents of strongly interacting particles has long been conventional dogma. Less well known, but no less important, is the role of quarks in nuclei. A recent meeting in Austria looked at this frontier between particle and nuclear physics.

35 years ago, in the autumn of 1963, the idea of quarks as the elementary constituents of all nuclear and hadronic matter was conceived, both at Caltech in Pasadena by Murray Gell-Mann and at CERN by George Zweig. However, it took about another 10 years before it was realized that with the help of the quarks a relativistic field theory of all strong interaction phenomena could be formulated: quantum chromodynamics (QCD).

Today QCD is the basic and comprehensive theory of strong interactions, covering both nuclear and particle physics. However, solving QCD at low and at high energies requires different approaches, and attempting to describe strong interaction phenomena via QCD in both nuclear and in high-energy physics remains a great challenge.

This problem was highlighted recently when about 60 particle and nuclear physicists working in hadron physics met for a symposium on "Quarks in Hadrons and Nuclei" in the unusual setting of the Hall of Armed Knights of the thousand-year-old Rothenfels castle above the small town of Oberwölz in Styria, Austria.

Topics

Physics topics included constituent quark models, structure functions of hadrons, spin structure of the nucleon, meson-baryon physics, chiral perturbation theory, diffractive processes, lattice gauge theory, quark masses etc.

The meeting began with a general historical account by Harald Fritzsch (Munich) of the development of strong interaction theory. This history dates back to a 1932 paper on the need for a new strong force inside the atomic nuclei by Werner Heisenberg, and cul-

minates in the formulation of the fundamentals of QCD in 1972–73. The property of "confinement" shows that quarks exist as quasi-free particles when close together, but feel increasingly strong binding forces when they try to move apart.

Among the many facets of QCD that have emerged over the past 25 years is the problem of quark-gluon dynamics at low energies, responsible for the properties of hadrons and nuclei as building blocks of matter. Effective models of QCD (such as the constituent quark model) work remarkably well at low energies though a fundamental derivation from fundamental QCD is still lacking.

At low energies the nucleon appears to be a composite structure of three valence (constituent) quarks, while at high energy it can appear as a complicated mixture of current quarks and antiquarks as well as gluons. These dual pictures of the nucleon and the link between them are still not fully understood.

Progress and new attempts in the description of hadrons in terms of constituent quarks were reported by M Beyer (Rostock) and W

Reconciling the quark/gluon picture of high-energy particle physics with the properties of nuclear matter is not straightforward. The narrow bridge was crossed in September when particle and nuclear physicists met in the unusual setting of the Hall of Armed Knights of the thousand-year-old Rothenfels castle above the small town of Oberwölz in Styria, Austria.

Lucha (Vienna). The delicate problem of the composition of the spin of the nucleon from low to high energies was addressed from the experimental and the theoretical sides. While the constituent (valence) quark model suggests that (most of) the spin of a nucleon should arise from the quark degrees of freedom, experiments – described by K Rith (Erlangen) – indicate that the quark contribution to the nucleon spin is only about 30%. Theoretical attempts to solve this problem were reviewed by M Karliner (Tel Aviv). A Vogt (Leiden) reported insights from deep-inelastic structure functions. Whatever the final solution to the nucleon spin problem will be, it is clear that gluonic degrees of freedom plays a role and that gluons are either directly or indirectly contributing to the nucleon spin. (This is currently being addressed by the HERMES experiment at DESY's HERA electron ring – November, page 10.)

Since the early days of QCD physicists have predicted the existence of hadronic objects – "glueballs" – formed primarily of gluons rather than quarks, or "hybrids" with both quarks and gluons as constituents. These aspects of QCD and their connections with elastic-like diffractive processes were covered by F Close (CERN), P Landshoff (Cambridge), and P Minkowski (Bern). While the existence

of glueballs and hybrids is now generally accepted on theoretical grounds, it is only recently that coherent evidence has begun to emerge supporting predictions that the simplest gluonic mesons exist between 1.4 and 1.8 GeV.

Some basic properties of hadrons and nuclei, such as their masses, are directly related to the structure of the hadronic vacuum, which influences the otherwise difficult-to-calculate (nonperturbative) aspects of QCD. The influence of the hadronic vacuum can be described via QCD sum rules. M Shifman (Minneapolis) gave an account of recent developments and also reviewed 20 years of the sum-rule technique. R Rückl (Würzburg) described specific applications for exclusive decays of heavy mesons. The question of quark masses was covered by M Jamin (Heidelberg).

Lattice QCD

Gauge theory using an underlying lattice rather than a continuum, pioneered by Kenneth Wilson to describe the otherwise difficult-to-handle aspects of QCD, has undergone a tremendous development. A number of variants have been developed and it became clear from the talks of F Jegerlehner (DESY, Zeuthen) and A Schäfer (Regensburg) that lattice QCD will continue to be a powerful tool for QCD problems at low energies.

Another salient feature of low-energy QCD is the role played by topological properties of gluonic field configurations like colour-magnetic monopoles and instantons. They might be responsible for

quark confinement and also play a decisive role in the formation and dynamics of the lightest mesons, as was discussed by F Lenz (Erlangen) and H Reinhardt (Tübingen).

In the same context, with respect to meson-baryon physics and more generally any hadron properties, consideration of chiral (left-handed and right-handed) symmetry and chiral-symmetry breaking turns out to be important. G Ecker (Vienna) gave an instructive summary of chiral perturbation theory, and P Kroll (Wuppertal) addressed exclusive charmonium decays.

While QCD relies on quarks and gluons, quark and gluonic degrees of freedom are relatively inconspicuous for the dynamics of nuclei. However, as emphasized by A Thomas (Adelaide), nuclear matter cannot be described solely by nucleons moving in a nuclear potential; quark and gluonic aspects also need to be taken into account.

The symposium was co-organized by the Institutes for Theoretical Physics of the Ludwig-Maximilians-Universität Munich and the Karl-Franzens-Universität Graz, with H Fritzsche and W Plessas chairing the organizing committee. It was funded by the Province of Styria, the Austrian Federal Ministry for Science and Transportation, and the German W.E. Heraeus Foundation. It was also supported by sponsors from commerce and industry as well as the town of Oberwölz.

H Fritzsche, Munich and W Plessas, Graz.

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