THE CLOUDY BAG MODEL

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A COMPILATION OF PUBLISHED PAPERS
PRESENTED FOR THE DEGREE OF
DOCTOR OF SCIENCE
IN
THE UNIVERSITY OF ADELAIDE

OCTOBER 1983

[Signature] 11-4-83
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As a method of classification of the observed, strongly interacting particles the quark model was invented in the mid-sixties. However, the general belief that quarks are the fundamental constituents of hadronic matter (not simply a useful mathematical device) did not come for a further decade. The discovery of the J/ψ, and the evidence for pointlike constituents inside hadrons from SLAC, were the major reasons for acceptance. However, the emergence of a local gauge theory for the strong interactions of coloured quarks (QCD) was also an important factor.

Amongst the attractive features of QCD were the proof that it is asymptotically free, and the strong possibility that its infrared behaviour could be confining. Thus QCD suggested the solution to two problems simultaneously. Quarks had not been observed because of confinement, however they could still behave as free particles inside hadrons (and hence yield structure functions that scale).

The mid-seventies saw the construction of many phenomenological models of hadron structure, motivated by QCD. The non-relativistic quark model (NRQM) is the most widely used, because of its simplicity and its phenomenological success. However it suffers from terrible inconsistencies through its non-relativistic nature, with typical quark momenta larger than the corresponding rest mass.

The MIT bag model had two major advantages. It was constructed in a completely covariant way and the introduction of massless quarks was no problem. Furthermore, because the quarks were free inside the bag, the phenomenon of scaling, at least for values of Bjorken-x greater than (2πR)⁻¹, was built in. Amongst the early successes of the MIT bag model were the agreement within (20–30)% for baryon magnetic moments, and the excellent value of ga/gv = 1.09 –
compared to 1.66 for non-relativistic models.

Almost immediately it was realized that the MIT bag model had one important flaw. Massless QCD has an exact chiral symmetry which is broken in the MIT bag model. Indeed, it seems that any model which confines quarks would also break chiral symmetry. Even though this problem was noticed in 1974 by Chodos and Thorn, and by Inoue and Maskawa, little more was done until 1979, when Brown and Rho raised the issue in a major way.

It is a fundamental belief in nuclear physics that the long-range N-N force is well described by pion exchange. In 1978 Gerry Brown and Mannque Rho realized that chiral symmetry could be restored in the bag model by coupling the pion field to the quarks at the bag surface. Their hope was that the pressure exerted by this external Bose field would compress the bag to a radius small enough that nuclear physicists could continue to ignore quark degrees of freedom, as they had done until that time.

Until 1979 my major work had been in intermediate energy physics, where the pion-nucleon interaction was usually treated as a phenomenological input. On a flight back from a conference in Houston in February 1979, Jerry Miller and I realized that the Brown-Rho approach offered a path to a much deeper understanding of the pion-nucleon interaction. Paper I was completed within a few months, but took quite a while to be published. The editor at Physical Review Letters said that the work was possibly more significant than the original MIT bag, but that it was a bit complicated for the general audience of PRL. Eventually it was published in Physics Letters, but only after the title was changed from "Pion-Nucleon Scattering in the Cloudy Bag Model" to "Pion Nucleon Scattering in the Brown-Rho Bag Model". (The editor of Physics Letters is in the same corridor at SUNY
Stony Brook as Gerry Brown.

That first paper was confused as to how exactly the pion field should be treated. We could not decide whether it should be quantised or not, or whether a renormalisation program was appropriate. By the time paper 2 appeared in December 1980 all of this was resolved. The discussion of renormalisation of the CBM which appears there is mine, and represented the major foundation stone for all that followed. In that paper we gave a definitive answer concerning the nature of the $\delta(1231)$ resonance, which is now universally accepted. This paper alone has been cited more than one hundred times since its publication, and has prompted an enormous amount of subsidiary theoretical work.

The later papers discuss the implications of our work for nuclear physics and for hadron structure. With respect to nuclear structure, we found that the bag radius (typically $1 fm$ in the MIT bag model) was not compressed much by the pion field. This implied that quark degrees of freedom would play an important role in the short-distance $NN$ force, and modify the conventional picture of nuclear structure in a major way. This view was almost heresy in 1980, and led to heated arguments with the Stony Brook group at various international conferences. In 1985 it would be hard to find such an argument. Plans for new accelerators in Canada, the U.S., France and Germany are now largely based on the need to understand better the role of quarks in the nucleus.

Amongst the papers included here, I would mention only a few specifically. Paper 3 represents work done while on study leave at the University of Melbourne and during a short visit to this University. It was a crucial step for most of the recent developments involving $KN$ and $\bar{K}N$ systems. In it I showed that instead of coupling the pion field to the confined quarks only at the bag surface, one could transform the
theory to a form where the pions coupled throughout the bag volume. Remarkably, the second version gives the same \( B^m \) coupling constants and form-factors (as long as the quark radial orbit is unaltered). However it also gives the correct results for the \( s \)-wave pion-nucleon scattering lengths, and higher order corrections to it are much more convergent. Indeed, this new version of the CBM has largely superseded the original.

To conclude this introduction I should mention a major theme of the last two years. Deep-inelastic lepton scattering is the tool "par excellence" for investigating the internal structure of matter. Paper 19 puts a new limit on bag size using DIS data. Paper 26 suggests a new measurement which would establish the presence of an exotic, \( s \)-quark component in the deuteron. Finally, papers 20, 28, 29, 31 and 33 deal with the natural extension of all the earlier CBM work towards an understanding of the EMC effect, which is the first clear evidence of a change in the quark structure of a nucleon when imbedded in a nuclear medium.

Note: The published work reproduced here represents in many cases collaborative work with students*, post-doctoral fellows and professional colleagues. In every one of the papers included here I have been at the very least an equal partner in the research. I feel that the international recognition of this, through more than 10 invitations to present talks on this work (in plenary session) at international meetings in the last five years, is sufficient testimony.

*Dr. S. Téberge was my Ph.D. student at the University of British Columbia, and the papers with him as co-author were submitted with his thesis in partial fulfilment of the requirements for the Ph.D. there in 1982.