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On the quark-gluon plasma and some other issues

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Big efforts are underway, started 1997 or before, to get quark-gluon plasma in high-energy nucleus-nucleus collisions within the ALICE experiment at CERN, scheduled to take off sometime around 2008. It is hoped to get cca $10^3 GeV/fm^3$ an energy density, which is about this figure per nucleon (nucleon radius $\sim 1.5fm$, $1fm = 10^{-15}m$).

According to quantal chromodynamics matter consists of various kinds of quarks (1/2-spin fermions) interacting strongly with gluon radiation (bosons). In addition, the unified model assumes the weak interaction of various families of fermions, quarks and leptons included, carried through the gauge bosons, together with the electromagnetic interaction mediated by photons.

It is sold out around as a curiosity the asymptotic freedom of the quantal chromodynamics, which would mean that quarks and gluons are only free at high energies, as, for instance, those exceeding the nucleon rest energy ($\sim 1GeV$). For lower energies, quarks and gluons would only be bound into various massive hadrons, like nucleons, mesons, etc. To get the free quark-gluon plasma by imparting to the nucleons such high energies motivates the ALICE experiment.

To get free particles there is indeed need of high energies, which localize them, and enable one to speak of them in terms of free particles, since for high enough energies no particle cares anymore of any other interaction, and will behave freely. Unfortunately, the idea of a pure, absolute and neutral vacuum has no correspondent in reality, as the vacuum is full of interaction, polarization, etc, and a free particle without no interaction is meaningless. It is only when it gets enough energy for not feeling anymore other interactions, and gets thereby localized enough, that we may speak with sense of free particles. So, the asymptotic freedom is no big deal.[1]

Technically, the asymptotic freedom is based on renormalizing the coupling constant of the strong interaction, and checking that it decreases on increasing the energy scale. This technicality has been pointed out long before in quantal electrodynamics, and is probably best illustrated by Landau pole;[2] the coupling constant, like the electron charge, goes zero with the inverse of the logarithm of the scale energy; and it is infinite for the characteristic scale, which leads to admiting infinite bare coupling constants, and to subtract arbitrarily and indefinetely infinities in higher orders of the perturbation theory, in order to make some sense out of such computations. If the scheme works, we say that the theory is renormalizable. But we do not know yet clearly the origin, or the cause, of the renormalizability (or non-renormalizability; probably, the global covariance). Such an uncomfortable situation leads many to admit that the quantal electrodynamics, and quantal chromodynamics so much the more, are not yet fully consistent theories. Actually, the

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[1] This is the positivist standpoint of physics, made illustrious by relativity, or quantal mechanics, in contrast to the metaphysical view which deals with ideas that cannot be measured, or measurable.

[2] Which tells that the corresponding nobel prize was futile ("ious").

answer lies into the renormalization of the fields starting with higher orders of the theory of perturbation, the notion of quasiparticle and lifetime, which shows that the first non-vanishing orders of perturbation is in fact all what we need, and makes sense.

When renormalizability works, as for quantal electrodynamics, it works in any finite order of perturbation, where undetermined infinities are brought at work. A fully-summed theory of perturbation would not be renormalizable, precisely because the infinities are many and different for each order. It is a "nullifying", or "zeroing" interaction theory. Divergent radiative corrections mean the particles are short living on high energy scale, which, consequently brings no contribution to the free particles, leaving us thus with the first non-vanishing orders of interaction. For lower energies, finite corrections can be brought by higher orders, in special circumstances (like external fields, as for Lamb shift and anomalous magnetic moment), but they are ridiculously small. Lets do not forget that both the magnetic momentum and the energy levels do precisely occur in external fields, so self-energy and polarization must indeed be computed in the non-relativistic limit of bound states and macroscopic fields; the small change in the later give small changes in the former.[3]

The main effort in studying the quark-gluon plasma is directed towards getting hadronic mass by interaction proceses. Lattice chromodynamics have been invented to this end, in order to deal with the infinities of the perturbation theory by discretizing the space and time. Though, as seen from the above, there would not be any need. Mass is getting by symmetry breaking, the intrinsic symmetries break out and this is a well-known mechanism of getting mass. One needs for that a macroscopic condensation of the fields carrying the interaction, and, substantially speaking, this mechanism is a statistical one, requiring a rich statistics, either quantal, or thermal. The notorius examples are the Higgs mechanism and superconductivity. But hadrons do not get mass as many, they get it just individually. The mechanism of symmetry breaking simply is not the proper one.

The nuclear quark-gluon plasma is a hot matter. Simple estimation show that for igniting it one needs a threshold energy of $\sim 200MeV$ per quark. In addition, the gluons dominate the plasma, so a gas of fixed number of quarks would not do. In fact, the excitation energies envisaged in ALICE experiment are very high, as high as quarks and gluons are in mutual equilibrium, and plasma is an ideal gas of ultrarelativistic quarks and radiation. Such hot a matter is definetely not only statistical, but mainly thermal. And, as it is well-known, the statistics in thermal matter cares little about particular interaction, and, likewise, the condensation has nothing to do with the particular hamiltonian and its symmetry breaking. It is just a phase transition described statistically. This is why the lattice quantal chromodynamics would have no relevance on the hadronic output of the ALICE experiment, which would measure distributions of the hadronic yield. In addition, symmetry breaking is usually associated with second-kind phase transitions, going continuously with the order parameter, while hadronization in a quark-gluon mass is a first-kind one, like drops of liquid appearing in an expanding, cooling vapour gas. And the process is rather a phase quilibrium, and a sudden change.

Getting nucleons, or hadrons, or, in general, composite or bound states out from the quantal chromodynamics, *i.e.* out from free quarks, free gluons and their interaction is however another matter. It is indeed a quantal matter, in contrast to the hadronization of the quark-gluon plasma, which is a thermal and statistical matter. And, as we know, "more is different", and one may say quite different. Such bound states may originate in the non-linear (quadratic) term in the gluon interaction, required by the local gauge invariance of the Yang-Mills fields. Because, if we require local invariance (covariance), we admit that things change locally, which means they are defined locally, *i.e.* they are particles. If they are particles they are no more waves, and no quantal. A

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[3] Which again illustrates that the only existing things are those measurable.

situation quite similar with the local covariance of Einstein's theory of gravity, which impedes its quantization. Indeed, once bound, the quarks and gluons are no more quantal, the gluons suffer a condensation and the quarks a massification, which means that we are far away from the quantal behaviour. An effective interaction may even be derived, very much alike as the Coulomb potential arising by the condensation of the virtual infrared photons. But this is another, and different, matter. One of the big difference between condensation by symmetry breaking on one hand and by interaction on the other is that the former may not necessarily be localized, and could better be described as correlation, having no potential of interaction, *i.e.* no local potential of interaction, while the later is localized indeed. In the former case the correlation is extended, and the Higgs boson is better described as an extended field. Similarly, the Cooper pairs in the superconductor are in fact an extended field of order parameter. In both cases the statistical component is a prerequisite. While a macroscopic occupation of soft gluons would lead to non-relativistic potentials of interactions, bound states of composite non-relativistic quarks, and the most desired residual interaction between the nucleons.
