Thesis resume

Quark-antiquark interactions in background magnetic fields

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Introduction The properties of strong interacting matter in the presence of large external fields have attracted much interest in the recent past. The investigation of such properties is relevant in different physical conditions. For example, it is believed that strong magnetic fields, of the order of 10^{16} Tesla ~ 1 GeV^2, may have been produced in the early Universe. In addition, slightly lower magnetic fields, up to about 10^{15} Tesla, are expected to be created in non-central ultra-relativistic heavy-ion collisions. In this context, the theory representing our current understanding of strong interaction, the Quantum Chromodynamics (QCD), allows to predict many important results. As regards the investigation in the non-perturbative regime, the lattice formulation (LQCD) reveals to be one of the most suitable approach. Within this framework, the properties of the strong interacting matter in the presence of external magnetic field have been studied extensively, leading to relevant results such as the effects on the QCD phase diagram at finite temperatures and those on of deconfinement and chiral system restauration.

The work presented in this thesis lies exactly in this context. It is based on the study presented in a very recent paper[1] about the properties of the confining potential between two heavy quarks in the presence of a constant and uniform external magnetic field, performed within the LQCD formulation at zero temperature. It has been found that the potential is anisotropic for non-vanishing magnetic fields, showing different behaviours in the directions transverse and parallel to the external field. In particular, adopting the standard Cornell parametrization, i.e. a linear rising confining term (σr) supplied with a Coulomb-like one (α / r)

$$V_C(r) = -\frac{\alpha}{r} + \sigma r \tag{1}$$

it has been found that anisotropies emerge in both the string tension σ and in the strength of the Coulomb coupling α of the static potential, which acquire a non-trivial dependence on magnetic field, i.e. $\sigma = \sigma(\theta; B)$ and $\alpha = \alpha(\theta; B)$ with θ azimutal angle with respect to the direction of B.

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Controlling idea and methods The original study proposed in this thesis is focused on the phenomenological effects that such anisotropies may produce. The main idea is that the observed behaviour of the static quark-antiquark potential in the presence of strong magnetic fields should affect the observables directly related on it. To this aim, it has been chosen to follow two distinct lines of investigations. The first involves the direct effects of the anisotropic static quark-antiquark potential on the energy levels, i.e. the masses of the heavy-meson spectrum; the second, instead, generalizes the investigation at finite temperature and it focalized on the behaviour of the correlator between the so-called Polyakov loops $L()$, defined as the temporal loop made up by the parallel transports (gauge links living) living on the lattice, which is strictly connected with the static potential.

In the first case, the work has been based on an non-relativistic approach for describing the heavy-mesons, i.e. the bound states $c\bar{c}$ and $b\bar{b}$. The reason lies exactly in the nature of the quenched potential, which is formally valid in the infinite mass limit and hence represents a suitable parametrization of the heavy quark-antiquark interaction. The model describing the dynamics of a bound state in an external magnetic field has been solved making use of a numerical algorithm (based on a finite-difference scheme) allowing the extraction of both eigenstates and eigenvalues through an Euclidean finite-time step evolution. This procedure, supplied with a state-mixing algorithm, has provided the computation of the masses of the lower part of the heavy-meson spectrum, i.e. that corresponding to the 1S and 1P states. Simulations have been performed in the range $B = 0.1 - 0.3$ GeV^2, both considering or not the presence of the anisotropy, in order to check and separate the possible mass differences.

As regards the second part of this study, it is focused on the effects of external magnetic fields at finite temperature and, hence, representing a natural continuation of the investigation of the anisotropy. The expectation values of the Polyakov loop correlators have been extracted from lattice configuration samples corresponding to a 2+1 lattice QCD theory, i.e. with dynamical quarks u, d, s such that $m_u = m_d \neq m_s$. In order to check the possible effect of the magnetic anisotropy, correlators been computed separating the contributions along the spatial directions transverse and parallel with respect to the applied external magnetic field. Such a procedure also requires the application of a specific strategy to decrease the noise due to the UV fluctuation on the lattice (gauge link smearing). Simulations have been performed for different magnetic fields of the order of $B \sim 10^{15}$ Tesla and for a single lattice volume 32×8 at the temperature of about $T \sim 140$ MeV, i.e. slightly before the expected chiral and deconfinement transitions.

Obtained results In both cases, the study suggests that the presence of an external strong magnetic field has relevant effects. Concerning the heavy-meson mass spectrum, the model predicts that the anisotropy, within the range investigated, may increase the mass value by an amount of the same order (or, in some cases, slightly higher) of those related to the effect of the magnetic field only. These are expected to be of the order of about $20 - 30$ MeV in the case of the charmonium spectru, and of about $1 - 5$ MeV for bottomonium states. In addition, the model predicts also non-trivial mixing between the particle states, depending on the module of the external field, which may creates concrete effects on, for example, the decay rates or the possible decay channels. Non-negligible effects have been also found, at finite temperature, on the correlator between Polyakov loops. Their behaviour for large distances seems to agree with the expected picture of a decreasing of the temperature of the confinement-deconfinement crossover in the presence of an external magnetic field. As regards the static quark-antiquark potential, a curve fitting procedure of the data suggest that for $B \neq 0$ there is a clear splitting between the shapes in the directions parallel and orthogonal with respect to the magnetc field axes. At the level of the string tension σ or the parameter α, the anisotropy effect is more noticeable and, as regards in particular the string tension, up to about $20-25\%$ for $|e|B \sim 1$ GeV^2.

Such a study is clearly not exhaustive. Indeed, there are several lines of investigation which may be followed. As concerns the heavy-meson mass spectum, for example, one may try both to improve the non-relativistic model or to proceed with a more quantitative investigation about the reliability of a measurement of the observed effects. At finite temperatures, possible prospectives are more. Indeed, the study may be generalized to a wide range of both temperatures or densities, leading to a more detailed description of the possible effect on the QCD phase diagram.

References

[1] C. Bonati, M. D'Elia, M. Mariti, M. Mesiti, F. Negro, and F. Sanfilippo. Anisotropy of the quark-antiquark potential in a magnetic field. *Phys. Rev. D*, 89(11):114502, 2014. doi:10.1103/PhysRevD.89.114502.