Available online at www.sciencedirect.com

ScienceDirect

Nuclear and Particle Physics Proceedings 270–272 (2016) 185–189

www.elsevier.com/locate/nppp

Thermo-magnetic behavior of the quark-gluon vertex *

Alejandro Ayala[a,b], J. J. Cobos-Martínez[c], M. Loewe[d,b,e,1], María Elena Tejeda-Yeomans[f,a], R. Zamora[d]

[a] Instituto de Ciencias Nucleares, Universidad Nacional Autónoma de México, Apartado Postal 70-543, México Distrito Federal 04510, Mexico.
[b] Centre for Theoretical and Mathematical Physics, and Department of Physics, University of Cape Town, Rondebosch 7700, South Africa.
[c] Instituto de Física y Matemáticas, Universidad Michoacana de San Nicolás de Hidalgo, Edificio C-3, Ciudad Universitaria, Morelia, Michoacán 58040, México.
[d] Instituto de Física, Pontificia Universidad Católica de Chile, Casilla 306, Santiago 22, Chile.
[e] Centro Científico-Tecnológico de Valparaíso, Casilla 110-V, Valparaíso, Chile.
[f] Departamento de Física, Universidad de Sonora, Boulevard Luis Encinas y Rosales, Colonia Centro, Hermosilla, Sonora 83000, México

Abstract

The thermo-magnetic corrections to the quark-gluon vertex in the presence of a weak magnetic field are calculated in the frame of the Hard Thermal Loop approximation. The vertex satisfies a QED-like Ward identity with the quark self-energy calculated within the same approximation. It turns out that only the longitudinal vertex components get modified. The calculation provides a first principles result for the quark anomalous magnetic moment at high temperature in a weak magnetic field. The effective thermo-magnetic quark-gluon coupling shows a decreasing behavior as function of the field strength. This result supports the observation that the behavior of the effective quark-gluon coupling in the presence of a magnetic field is an important ingredient in order to understand the inverse magnetic catalysis phenomenon recently observed in the lattice QCD simulations.

Keywords: Chiral transition, Magnetic Field, Quark-gluon vertex, Quark anomalous magnetic moment

1. Introduction

Recent lattice QCD results, with 2+1 quark flavors, indicate that the transition temperature measured from the behavior of the chiral condensate and susceptibility, as well as from other thermodynamic observables such as longitudinal and transverse pressure, magnetization and energy and entropy densities, decreases with increasing magnetic field [1, 2, 3]. This result was called *magnetic anticatalysis*.

Recently, we have shown, in a natural way, how the decrease of the coupling constant with increasing field strength can be obtained within a perturbative calculation beyond the mean field approximation. Notice that such a behavior cannot be achived in the mean field approximation [4]. This was done both for the abelian Higgs [5] model as well as for the linear sigma model [6] where charged fields are subject to the effect of a constant magnetic field. This behavior introduces a dependence of the boson masses on the magnetic field inducing then a decreasing behavior of the critical temperature for chiral symmetry breaking/restoration. Going now into QCD, in order to to establish if a similar behavior takes place, a first step would be to determine the finite temperature and magnetic field dependence of the coupling constant.

The discussion of the thermal behavior of systems involving massless bosons, such as gluons, in the presence of magnetic fields is quite subtle. Unless a careful

*Talk given at 18th International Conference in Quantum Chromodynamics (QCD 15, 30th anniversary), 29 june - 3 july 2015, Montpellier - FR

Email addresses: ayala@nucleares.unam.mx (Alejandro Ayala), j.j.cobos.martinez@gmail.com (J. J. Cobos-Martínez), mloewe@fis.puc.cl (M. Loewe), elena.tejeda@fisica.uson.mx (María Elena Tejeda-Yeomans), rrzamora@uc.cl (R. Zamora)

[1] Speaker, Corresponding author.

http://dx.doi.org/10.1016/j.nuclphysbps.2016.02.037

treatment is implemented, severe infrared divergences associated to the effective dimensional reduction of the momentum integrals will appear. These divergencs are associated to the separation of the energy levels into transverse and longitudinal directions (with respect to the magnetic field direction). The former are given in terms of discrete Landau levels. Thus, the longitudinal mode alone no longer can tame the divergence of the Bose-Einstein distribution. In this context, recently it has been shown that it is possible to find the appropriate condensation conditions by accounting for the plasma screening effects [7]. Here we show that a simple prescription where the fermion mass acts as the infrared regulator allows to obtain the leading behavior of the QCD coupling for weak magnetic fields at high temperature, that is, in the Hard Thermal Loop (HTL) approximation. As a first step, we compute the thermo-magnetic corrections to the quark-gluon vertex in the weak field approximation. We use this calculation to compute the thermo-magnetic dependence of the QCD coupling. To include the magnetic field effects we use Schwinger's proper time method. We should point out that the weak field approximation means that one considers the field strength to be smaller than the square of the temperature but does not imply a hierarchy with respect to other scales in the problem such as the fermion mass.

2. Charged fermion propagator in a medium

The presence of a constant magnetic field breaks Lorentz invariance and leads to a charged fermion propagator which is function of the separate transverse and longitudinal momentum components (with respect to the field direction). Considering the case of a magnetic field pointing along the $\hat{z}$ direction, namely $\vec{B} = B\hat{z}$, the vector potential, in the so called *symmetric gauge*, is

$$A_\mu(x) = \frac{B}{2}(0, -x_2, x_1, 0). \qquad (1)$$

The fermion propagator in coordinate space cannot longer be written as a simple Fourier transform of a momentum propagator but instead it is written as [8]

$$S(x, x') = \Phi(x, x') \int \frac{d^4p}{(2\pi)^4} e^{-ip\cdot(x-x')} S(k), \qquad (2)$$

where

$$\Phi(x, x') = \exp\left\{ iq \int_{x'}^{x} d\xi^\mu \left[A_\mu + \frac{1}{2} F_{\mu\nu}(\xi - x')^\nu \right] \right\}, \qquad (3)$$

is called the *phase factor* and q is the absolute value of the fermion's charge, in units of the electron charge. $S(k)$ is given by

$$\begin{aligned} S(k) &= -i \int_0^\infty \frac{ds}{\cos(qBs)} e^{is\left(k_\parallel^2 - k_\perp^2 \frac{\tan(qBs)}{qBs} - m^2\right)} \\ &\times \left\{ \left[\cos(qBs) + \gamma_1\gamma_2 \sin(qBs)\right](m + \not{k}_\parallel) \right. \\ &- \left. \frac{\not{k}_\perp}{\cos(qBs)} \right\}, \end{aligned} \qquad (4)$$

where m is the quark mass and we use the definitions for the parallel and perpendicular components of the scalar product of two vectors a^μ and b^μ given by

$$\begin{aligned} (a\cdot b)_\parallel &= a_0 b_0 - a_3 b_3 \\ (a\cdot b)_\perp &= a_1 b_1 + a_2 b_2. \end{aligned} \qquad (5)$$

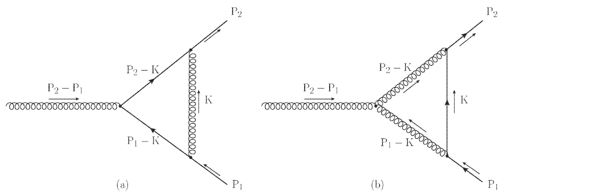

Figure 1: Feynman diagrams contributing to the thermo-magnetic dependence of the quark-gluon vertex. Diagram (a) corresponds to a QED-like contribution whereas diagram (b) corresponds to a pure QCD contribution.

Figure 1 shows the Feynman diagrams contributing to the quark-gluon vertex. Diagram (a) corresponds to a QED-like contribution whereas diagram (b) corresponds to a pure QCD contribution. The computation of these diagrams requires using the fermion propagator given by Eq. (2), which involves the phase factor in Eq. (3). It turns out, however, that this phase does not contribute. We refer the reader to the original article [9] where a proof of this fact is presented. Therefore, for the computation of diagrams (a) and (b) in Fig. 1, we can just work with the momentum representation of the fermion propagators since the phase factors do not contribute. The situation would have been nontrivial in case the computation had required a three fermion propagator closed loop [10].

3. QCD vertex at finite temperature with a weak magnetic field

To compute the leading magnetic field dependence of the vertex at high temperature, we work in the