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Inverse magnetic/shear catalysis

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Abstract

It is well known that very large magnetic fields are generated when the Quark–Gluon Plasma is formed during peripheral heavy-ion collisions. Lattice, holographic, and other studies strongly suggest that these fields may, for observationally relevant field values, induce "inverse magnetic catalysis", signalled by a lowering of the critical temperature for the chiral/deconfinement transition. The theoretical basis of this effect has recently attracted much attention; yet so far these investigations have not included another, equally dramatic consequence of the peripheral collision geometry: the QGP acquires a large angular momentum vector, parallel to the magnetic field. Here we use holographic techniques to argue that the angular momentum can also, independently, have an effect on transition temperatures, and we obtain a rough estimate of the relative effects of the presence of both a magnetic field and an angular momentum density. We find that the shearing angular momentum reinforces the effect of the magnetic field at low values of the baryonic chemical potential, but that it can actually decrease that effect at high chemical potentials.

1. The QGP subjected to magnetic fields and shear

The ability of current facilities [1–4] to investigate deconfined quark matter in the form of a *Quark–Gluon Plasma* (QGP), resulting from collisions of heavy ions, represents a major step forward, and it is vitally important that this form of matter be understood theoretically [5]. How-

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ever, collisions of these extended and complex objects produce a QGP which is not simple. In particular, while some collisions are *central*, others are *peripheral* ("off-center"), and this leads to several complications.

One such complication, which has received a great deal of attention, is that the QGP produced in a peripheral collision can be subject to an extremely large magnetic field [6–8]. The magnetic fields involved are so large that they can affect parameters that would otherwise be exclusively in the domain of the strong interaction, and this has led to predictions of various novel phenomena in the context of what is effectively a new branch of quantum chromodynamics [9] ("magnetochromodynamics").

In particular, there are very general theoretical arguments to the effect that magnetic fields of this order might affect the chiral/deconfinement transition, and particularly the (pseudo-)critical temperature at which the latter occurs (at zero baryonic chemical potential). It is thought that this could be due to a reduction of the "effective dimensionality" imposed by the magnetic field. This idea will be the basis of our discussions in this work.

Until recently, it was thought that the effect of strong magnetic fields would be to "catalyse" the chiral transition, resulting in a higher transition temperature[1]: this is "magnetic catalysis". However, lattice computations [11] suggest the opposite effect on the transition temperature: this is *inverse* magnetic catalysis — see for example [12,13] for recent discussions of this effect, and [14,15] for reviews. This might mean that the transition occurs at a lower temperature in a plasma produced by a peripheral collision than in a plasma associated with a central collision in the same beam; whether such an effect is actually observable remains to be seen.

Still more recently, it has been argued (for references, see again the reviews [14,15]) that analogous phenomena may also occur at non-zero values of the baryonic chemical potential, in particular, near to the critical point which is generally thought to exist in the quark matter phase diagram [16,17]. We shall consider the holography of this case too; it will be important for experiments in the near future.

The theoretical basis of inverse magnetic catalysis is not well understood, and constructing a convincing theory is a major objective of current theoretical research (see for example [18] for one set of suggestions). At this point, it is important to subject any theory of this effect to tests under a wide variety of conditions.[2] For example, recent lattice results [19] indicate that inverse catalysis holds even at ultra-high fields (well over 3 GeV^2, and perhaps even indefinitely), though there are other theoretical arguments to the effect that it might be replaced by magnetic *catalysis* at still higher field values [20]. This is of great interest for testing theoretical proposals, even though such high fields do not occur in collisions producing temperatures near to the transition temperatures.

Inverse magnetic catalysis is associated with the internal motion of the QGP when it is produced by a peripheral collision. But this internal motion is also associated with another phenomenon: *the plasma inevitably acquires a very large angular momentum* (per unit energy). This angular momentum can be associated with either rotation [21–24] (see [25] for the most recent developments) or shear [26–28]; the latter will be our concern here. The shearing motion is rep-

[1] In principle, the chiral and deconfinement transitions are of course different, and it is conceivable that magnetic fields might catalyze the chiral transition while yet driving down the deconfinement temperature. This has been discussed from a holographic point of view in [10]. Here we confine our attention to the standard picture in which the two transitions always occur in the same way.

[2] The simplest, indeed perhaps overly simple models, are the "magnetic bag models"; for a discussion of their drawbacks and uses, see [15].