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A New Phase for an Old Theory?*)

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In the last few years experiments colliding very heavy ions, at energies close to the Coulomb barrier, have reported a series of peculiar phenomena, involving unexplained line structures in the produced positron energy spectra and correlated e^+e^- and $\gamma\gamma$ signals (see Nature 331, 109; 1988). Although a great many theoretical speculations have been put forward concerning the origin of these effects, it is fair to say that no satisfactory solution is yet in sight. The most intriguing explanation for the puzzling heavy ion data so far, has been suggested recently by three different groups [1], who boldly argue that the phenomena seen are a manifestation of the formation of a new phase of QED. QED being a venerable theory, whose predictions are tested to eight decimal places, this suggestion has been greeted with considerable skepticism by many theorists, who mostly react to it as if they were told that their favorite aunt was seen hanging out with a punk rock group.

To better gauge the plausibility of this idea, it is necessary to understand more fully both the experimental situation and the phenomenological and theoretical background. The sharp line structure ($\Gamma_{e^+} \lesssim 100$ keV) around $E_{e^+} \simeq 350$ KeV, observed in the early experiments of the EPOS [2] and ORANGE [3] collaborations at GSI-Darmstadt, appeared to be essentially independent of the total charge $Z = Z_1 + Z_2$ of the colliding ions. This important feature has also emerged in further experiments carried out by

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*) Contributed to the News and Views section of Nature

both collaborations. Employing a double solenoid spectrometer, EPOS has found various sharp lines in the sum energy spectra of positrons and electrons, with kinetic energy near 350 KeV, emitted oppositely to each other [4]. The simplest kinematical explanation for these observations is that the correlated signals correspond to the decay of some neutral objects, produced at rest in the heavy ion CM system. With this interpretation, the sum energy peaks, seen in U + Th collisions by EPOS, correspond to states of invariant mass of 1823 ± 8, 1782 ± 20 and 1630 ± 8 KeV. Furthermore a very recent EPOS run [5] with U + Ta has identified a prominent sum line, corresponding to an invariant mass of 1770 $\pm$ 8 KeV, which has a clear correspondence with what was found in U + Th. The ORANGE collaboration, with an apparatus of improved resolution [6], has reported multiple peak structures in the single positron spectra produced by heavy ions, ranging from Pb + Pb to U + U. For all these Z's, the line structures found appear to be essentially Z independent and arise at $E_{e^+} \simeq 250$ KeV, $E_{e^+} \simeq 340$ KeV and $E_{e^+} \simeq 410$ KeV. In the last months, a double ORANGE spectrometer was installed. The first coincidence data obtained with it in U + U collisions [7], shows a four standard deviation peak at $E_{e^+} + E_{e^-} = 810$ keV, for back to back e^+ and e^-. This nicely agrees with the highest invariant mass state found by the EPOS collaboration. The last important piece of experimental information comes from an experiment carried out in the super HILAC at LBL.[8] In this experiment, done with U + Th, a correlated $\gamma\gamma$ signal was found - with the γ's being back to back in the CM system - corresponding to the decay of an object of invariant mass of 1062 KeV. Of particular significance, the width of the correlated $\gamma\gamma$ peak is extremely sharp: $\Gamma_{\gamma\gamma} \lesssim 2.5$ KeV, more than a factor of 10 sharper than the correlated e^+e^- widths.

Several aspects of the data fit nicely with the idea that some kind of phase transition has taken place:

i) The peaks seem to appear only in the strong, and stronly varying, electromagnetic field environment of the heavy ion collisions, as no similar phenomena has been seen in beam dump searches [9].

ii) The narrow width of the signals points to the formation of soliton-like bubbles of a new phase, whose lifetime is much longer than the characteristic time in which the heavy ions experience substantial acceleration (2×10^{-21} sec). Indeed, a width of 2 KeV corresponds to an interval of 2×10^{-19} sec, a time so long that by then the ions are already 10^4 fermi apart!

iii) If the heavy ion collisions were to trigger the formation of solitonic regions of a new phase of matter, it is likely that there should be several such excitations, naturally explaining the multiple peaks seen.

The authors of Ref. 1 essentially used these arguments, plus the Z independence of the observed signals, to argue on phenomenological grounds for the existence of a new QED phase. As further ammunition in favour of this interpretation, they adduced the mounting theoretical evidence for the existence of a strong coupling phase of QED, garnered both from comprehensive studies of the Schwinger Dyson equations by the Kiev School [10] and by recent lattice calculations [11]. The latter, in particular, give clear indications that QED has a strong coupling (confining?) phase, in which chiral symmetry is spontaneously broken by the presence of e^+e^- condensates. It seems to me, however, that the existence of this strong coupling phase, is something of a red herring, for in the heavy ion collision $\alpha \simeq 1/137$ and is not of O(1)! For the new QED phase interpretation of the data to be sensible, it must be that as a function of an order parameter $\langle 0 \rangle$, depending on the external electromagnetic field, the phase transition point moves from strong coupling to weak coupling, as shown schematically in the Figure.

Unfortunately, there are some contrary theoretical indications to the above picture. Dagotto and Wyld [12] recently studied a compact version of QED in a strong Coulomb field on the lattice and found that the phase transition point, rather than moving

towards weaker coupling, moved toward stronger coupling. The strong electric field, apparently, tries to dissociate the pairs created, impeding the formation of the condensates responsible for the breaking of chiral symmetry, observed at strong coupling. Somewhat similar conclusions were reached by Solà, Wetterich and myself [13], in the much simpler case of QED in the presence of a space-time constant electromagnetic field. In this case also, even for very strong fields, no signal of a breakdown of QED is apparent. The essential point is that nonlinearities, whose growth may drive one to a new phase, only occur through the coupling of the external fields to the photons, via an electron loop. Thus, irrespective of the strength of the fields, one must always pay at least a factor of α ! These counterexamples notwithstanding, it appears worthwhile to continue exploring whether other external field configurations may drive QED to a new phase. Nevertheless, it is clear that the phase diagram shown in the Figure is certainly oversimplified.

We are not likely to know theoretically for some time if the heavy ion phenomena are connected or not to a new phase of QED. However, some phenomenological observations may clarify the matter sooner. The masses and widths of the observed signals should be an intrinsic property of the soliton bubbles of the new phase and therefore ought to be independent of detailed characteristics of the collision. However, the actual production cross section of the bubbles, being connected to the strength of an order parameter, should depend on the ion's charge, their velocity and their scattering angles. Furthermore, in general, variations in the signal by changing some parameter, like Z, should be correlated with those produced by changing some other parameter.

It is important to obtain clear experimental information on these issues. For instance, using as an order parameter the electromagnetic interaction energy [13], one predicts that the production cross-section for producing a soliton, folded with the heavy ion collision cross-section, is roughly independent of the ion's charge, velocity and scattering angle. Unfortunately, the data from EPOS and ORANGE are contradictory on these points, with the EPOS data being particularly sensitive to velocity but not to the charge and the ORANGE data showing just the opposite! Only when these points are settled, and the Z independence of all peaks is firmly confirmed, are we likely to know more about the possible existence of a new phase of QED. For the nonce, check on the whereabouts of your aunt.

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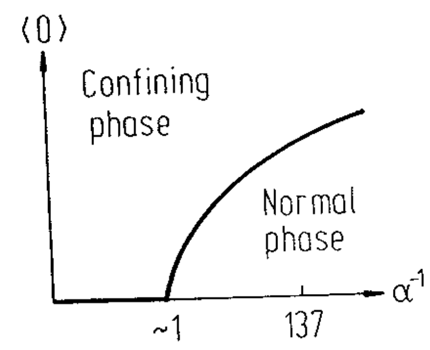

Figure: Speculated phase diagram for QED in the presence of a strong external electromagnetic field.