Exotic States in QED

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We suggest that electron and positron peaks seen in large-Z heavy-ion collisions originate in the decay of nontopological solitons consisting of a quasielectron and quasipositron which are formed in a new vacuum phase.

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The observation of peaks in the positron and electron spectra originating from the collision of heavy ions of large Z has created much interest.[1-4] Analysis of the data has suggested that one might be seeing the decay of a neutral particle of mass ~ 1.7 MeV.[5] There is also some *suggestion* of additional structure in the data.[1] If this additional structure is confirmed by more detailed experiments, the results would be even more puzzling.

In this work we suggest that the peaks seen result from the decay of a nontopological soliton formed in a new vacuum state created by the intense fields of the heavy ions. That is, we propose a phase change in the vacuum. The new phase would have a condensate of electrons and positrons as well as photons. (This condensate could serve to screen the intense fields of the heavy ions so that the new vacuum phase has only relatively small electric fields). We note that we do not understand the dynamics associated with the formation of this condensate. Once it is energetically favorable to form electron-positron pairs, we have a many-body problem which requires new techniques for its solution. With respect to the new vacuum we have new quasiparticles which we can call quasielectrons and quasipositrons. These quasiparticles are expected to have masses which are larger than the electron mass. The electron mass has a dynamical origin through the coupling of the electron field to a Higgs field. The Higgs field can be considered to describe a vacuum condensate which is characterized by a mass scale much larger than the one relevant to the new condensate considered here. Therefore we suggest that the quasielectrons and quasipositrons have the mass m_e plus an additional mass which arises from coupling to the new condensate.

We now turn to a description of nontopological solitons which arise from the coupling of these quasiparticles to the condensate order parameters.

Consider the following Lagrangean

$$\mathcal{L}(x)=\bar{\psi}(x)[i\gamma^\mu\partial_\mu-\tilde{m}_e-g\chi(x)]\psi(x)+\tfrac{1}{2}\partial^\mu\chi(x)\partial_\mu\chi(x)-\tfrac{1}{2}m_\chi^2\chi^2(x), \quad (1)$$

where $\psi(x)$ is the quasiparticle field and $\chi(x)$ is an order parameter (for the new condensate) which goes to zero outside the soliton. (The parameter $\tilde{m}_e=m_e+m_e^{\text{dyn}}$ is composed of the usual electron mass plus an additional dynamical mass arising from coupling to the new condensate.) The field equations are

$$[\partial^\mu\partial_\mu+m_\chi^2]\chi(x)=-g\bar{\psi}(x)\psi(x), \quad (2)$$

$$[i\gamma^\mu\partial_\mu-\tilde{m}_e]\psi(x)=g\psi(x)\chi(x). \quad (3)$$

The form for the potential term, $\frac{1}{2}m_\chi^2\chi^2(x)$, is the simplest one can use in the theory of nontopological solitons. If the dynamics of the condensate formation were understood, more complicated forms for the potential energy might be seen to be appropriate.

It is possible to make a fully covariant analysis of Eqs. (2) and (3) and such calculations have been performed to describe the structure of the ρ and ω mesons, and the states of the charmonium and Y systems.[6] We remark that solutions of Eqs. (2) and (3) are characterized by a coupling constant g and a mass ratio $m_\chi/\tilde{m}_2$. (We have reported solutions for $g\simeq 7$ and several values of $m_\chi/\tilde{m}_e$.[6]) Here we scale the previously reported results to obtain soliton solutions of mass 1.70 MeV. Some results are presented in Table I, where the quasiparticle mass is about twice m_e. The radius of the soliton is of the order of 10^{-2} Å or about 10^3 fm. This is a *very large object* when compared to the size of a nucleus and its existance would require that the vacuum phase is changed over quite a large volume. This radius of our object is, however, compatible with a characteristic length for the production of electron-positron pairs in supercritical fields.[7] For ex-

TABLE I. Mass parameters of the effective Lagrangean and mass of solitons of varying number of radial modes.

State	$\tilde{m}_e$ (keV)	m_X (keV)	$\left(\frac{m_X}{\tilde{m}_e}\right)$	m (keV)	Radius (rms) (10^{-2} Å)	Level spacing
1S	1110	274	0.247	1700	0.48	$m(2S)-m(1S)=380$ keV
2S	1110	274	0.247	2081	1.21	
1S	1024	90	0.088	1700	0.27	$m(2S)-m(1S)=161$ keV
2S	1024	90	0.088	1861	0.53	$m(3S)-m(2S)=99$ keV
3S	1024	90	0.088	1960	0.89	

ample, if one equates Ze^2/R to $2m_e$, for $Z=180$ one finds $R=265$ fm $=0.265\times10^{-2}$ Å. From inspection of Table I we see that the objects we have considered have this characteristic size. One may readily obtain level spacings in this model of the order of 100 keV. We suggest therefore that if our model is relevant one may expect additional peaks in the positron and electron spectra. For example, in Ref. 1 it is remarked that in the Th+Th system peaks are seen *both* at ~310 and ~370 keV and that *one may be observing more than a single structure.* Since one does not expect a large number of light neutral particles, the observation of additional structures in these experiments would lend support to a model of the type proposed here.

Further, the fact that the observed radiation seems to be consistent with a source moving with the center-of-mass velocity of the heavy ions[4] may also be understood in the context of our model. The narrow widths of the observed electron and positron lines are hard to understand if one assumes that one is observing the decay of a new elementary particle[8]; however, such narrow widths can be naturally accommodated in our model. Since our soliton is very large on a nuclear scale, and it *at rest* in the center-of-mass frame of the heavy ions, one expects only a minimal Doppler shift when observing the decay products in the laboratory. In our scenario the widths of the observed electron and positron lines would reflect (in addition to the small Doppler shift associated with the soliton momentum) the decay of the quasimolecular state of the two heavy nuclei which may be in contact long enough (10^{-19}–10^{-20} sec) to generate a new QED vacuum phase.

Finally, we may note that the near equality of the electron and positron energies indicates that one is seeing the decay of a single object. If the decay were taking place in the presence of the unscreened heavy ions it would be difficult to understand the data. Clearly, there are many questions which remain unanswered and more theoretical and experimental research is needed.

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