Coulomb problem for vector particles in gauge theories: when renormalizabilty may be not enough

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We argue that the renormalizability of a theory does not necessarily guarantee a reasonable behaviour at small distances for a nonperturbative problem, such as a bound state problem. As an example, we consider the Coulomb problem for W-bosons (spin $S = 1$) which incorporates a well known difficulty; the charge of the boson localized in close proximity to the attractive Coulomb center proves to be infinite. The vector boson falls on the Coulomb center. The phenomenon was discovered in the works of Tamm, Schwinger, Oppenheimer and others 66 years ago, and since then has been a nuisance for the theory.

We show that in pure QED the paradox is resolved by the polarization of the fermion vacuum, which brings in a strong effective repulsion at very small distances that eradicates the infinite charge of the boson at the Coulomb center [1]. This property allows one to define the Coulomb problem for vector bosons properly. It is interesting that the vacuum polarization for scalar and spinor particles produces only a weak effect while for vector bosons the situation is completely different; it produces the impenetrable potential barrier $\sim 1/r^4$.

In a renormalizable SU(2) theory containing vector triplet (W^+, W^-, photon) and fermion doublet ($F^+_{1/2}$, $F^-_{1/2}$) with large mass M (Coulomb centers) the vacuum polarization does not help; W boson falls to the Coulomb center to distances $r \sim 1/M$, where M can be made arbitrary large. Thus, the renormalizability itself does not prevent the theory from exhibiting poor behaviour at small distances. To save the situation, the theory needs additional fermions or scalars, which switch the ultraviolet behavior from the asymptotic freedom to the Landau pole.

Another interesting feature of vector bosons is that the charge density of a positively charged particle may be negative.

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[1] M. Kuchiev and V. Flambaum, Mod. Phys. Lett. **21**, 781 (2006); Phys. Rev. D **73**, 093009 (2006); Phys. Rev. Lett. **98**, 181805 (2007); hep-ph/0609194, hep-ph/0612366.