Mass Matters: The Rest Mass Issue, QCD, and the Pursuit of Dreams FREE

Friedwardt Winterberg; Antonio Ruiz de Elvira; Frank Wilczek

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Letters

Mass Matters: The Rest Mass Issue, QCD, and the Pursuit of Dreams

I have read with interest the essay by Frank Wilczek, "Mass without Mass I: Most of Matter" (PHYSICS TODAY, November 1999, page 11), but I do not believe that his idea of explaining rest mass solely by field mass is feasible. For purely dimensional reasons, the rest mass of any elementary particle must be expressed either in terms of another mass or a length. The only fundamental mass and length are the Planck mass and length. It is for this reason that the zero rest mass problem must involve gravity. It might be thought, for example, that one could replace the Planck mass with the electric charge of the electron, but doing so would mean having $mc^2 = e^2/r$ and $r = \hbar/mc$, leaving m undetermined.

The situation is not better in quantum chromodynamics. There, the field strength is determined by an equation of the form $F = \nabla \times A + g^{-1} A^2$, with A being the gauge potential and g the strong coupling constant. Setting $F = \phi$ (valid for large energies), one has a solution of the form $A = g/r$, with the energy $gA = g^2/r$. As before, with $mc^2 = g^2/r$ and $r = \hbar/mc$, the rest mass remains undetermined.

In Wilczek's 1999 *Nature* paper[1] (quoted in the essay), an expression of the proton rest mass is given by $m_{\text{proton}} \sim \exp(-k/\alpha)\, M_{\text{Planck}}$, where $\alpha \sim 1/25$ is the fine structure constant at the grand unification theory (GUT) scale, and $k = 11/2\pi$. If elementary particle physics at the Planck scale resembles hydrodynamics, a power law might be more appropriate.[2] With such a power law, the electron rest mass can quite well be expressed by $m_{\text{electron}} \sim (M_{\text{GUT}}/M_{\text{Planck}})^6\, M_{\text{Planck}}$. In hydrodynamics, large Reynolds numbers do occur—for example, in the Kármán vortex street, where one has $Re \sim 10^6$. If one employs the guess that $Re \sim (M_{\text{Planck}}/M_{\text{GUT}}) \sim 10^7$, one would have $M_{\text{electron}}/M_{\text{Planck}} \sim Re^3$.

References

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FRIEDWARDT WINTERBERG
University of Nevada, Reno

Having read Frank Wilczek's column, I would now like to pose some questions about the direction in which traditional physics seems to be going:

▷ Why is it more beautiful to have only one law, although it may involve ten dimensions, than to have several laws? I find beauty in diversity, and I feel no need for only one law. If we have as many as three or four laws, would nature be uglier?

▷ Wilczek speaks of replacing mass with energy. Can he explain why is it better, more beautiful, more economic, or whatever to do so? I am very happy with mass—and with multiple masses, at that.

▷ Why is it better to have an electron field with excitations than electrons? The existence of an electron field, constructed so that the electrons all have the same mass is not much better than the existence of 10^n electrons. I fail to see why a field is something better than a set of particles, if both agree with reality as we measure it.

▷ Wilczek states that the theory of color gluons is derived from a powerful symmetry principle. Can he explain why deriving physics from geometric principles is better than deriving symmetry principles from physics? Maybe he is happier being a mathematician, but perhaps he can also understand that other people are content to be physicists first and mathematicians second.

▷ Wilczek says that color gluons, as gravitons and photons, have no mass. But they have energy. Is it better to have energy than to have mass?

▷ Is it not more interesting and beautiful to have photons without mass, and particles with mass?

▷ Must we all follow the dreams of Hendrik Lorentz, Paul Dirac, John Wheeler, and Richard Feynman—or can we pursue our own dreams?

ANTONIO RUIZ DE ELVIRA
(ant@ws3.fsc.alcala.es)
University of Alcalá
Alcalá de Henares, Spain

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WILCZEK REPLIES: Friedwardt Winterberg's shrewd question goes directly to the heart of the matter. To answer it, I will have to recall the most profound concepts discussed in the two articles he cites—my essay in PHYSICS TODAY and my 1999 paper in *Nature*.[1]

If the strong coupling g were simply a numerical quantity, as it is in the classical limit of quantum chromodynamics, Winterberg's argument would be conclusive. When we treat QCD as a quantum theory, however, we learn that things are not so simple. We learn that the state we call "vacuum" teems with evanescent virtual particles and acts as a dynamic medium. As a result the vacuum reacts to charge, and the effective strength of the coupling to a test charge depends on the distance at which it is measured—namely, $g = g(r)$. This phenomenon, the running of the coupling, was originally derived theoretically by David Gross and me, and independently by David Politzer. On that basis, Gross and I proposed modern QCD as the theory of the strong interaction. The running of the coupling, in the predicted form, has now been verified in many precise experiments.[2]

Because of the running of the coupling, simple dimensional reasoning (as used by Winterberg) is invalid. Specifically, we can define a length l in terms of dimensionless quantities through the equation $g(l) = 1$. Having a length, we can derive a mass scale from $\mu = \hbar/lc$. All the masses of physical particles in QCD (or, more precisely, in QCD Lite) are then expressible as calculable numbers times this μ.

Dimensional analysis is not mocked, since QCD is powerless to compute μ itself. Indeed, the numerical value of that parameter has no significance within QCD! Different choices of μ will describe "different" worlds that behave identically, as far as their strong interactions are concerned, except for an overall change in the scale of length (or inverse mass). Just as parity symmetry asserts the physical equivalence of looking-glass worlds, so the scale symmetry of QCD does the same for magnifying-glass worlds.

We can check our understanding by determining whether calculated mass *ratios* agree with experiment. They do.[3]

Of course, other interactions, notably gravity, do involve the numerical value of μ. That is where the unification of couplings comes in. Given the limited space available here, I must refer readers seeking an adequate discussion to my 1999 *Nature* article[1] and to a PHYSICS TODAY article on unification that I cowrote with Savas Dimopoulos and Stuart Raby (October 1991, page 25). I will remark, however, that the logarithmic running of couplings that is central to this analysis is firmly rooted in basic principles of quantum field theory, and has been observed in many experiments. To be sure, we are extrapolating the observed results many orders of magnitude down in distance, or up in energy, beyond where we have direct evidence. But the depth of the roots, and the impressive success of the extrapolation, seem to me to make this circle of ideas much more consequential than vague hydrodynamic analogies.

Most of Antonio Ruiz de Elvira's questions call, in one way or another, for aesthetic judgments. Such questions go beyond rational argument. If I show you something I think is incredibly beautiful and you say "Nah!" or "So what?" subsequent rational argument may never bring us closer to agreement. I've been involved in discussions just like that, about atonal music. In discussing the beauty of the laws of physics, the situation seems much more hopeful, because the beauty of the concepts emerges more clearly with deeper understanding.

Here I will address only Ruiz de Elvira's third question. Electrons in various parts of the universe have undergone drastically different histories. Furthermore, new ones are created, and old ones are destroyed, in cosmic-ray reactions and nuclear decays. To postulate that all electrons have the same properties is, on the face of it, a complex *ad hoc* hypothesis. How much more satisfactory it is to understand that a single, uniform, and universal field is responsible![4]

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FRANK WILCZEK
Institute for Advanced Study
Princeton, New Jersey

Science, not Politics, Should Set Science Curriculum *in Toto*

Although I think the outrage of the scientific community about the Kansas decision regarding the teaching of evolution ("Scientists View Kansas Board's Decision as a Wake-Up Call," PHYSICS TODAY, November 1999, page 59) is more than justified, I disagree with the position taken by Fred Spilhaus, Molleen Matsumura, and others cited by reporter Jean Kumagai. They see the remedy in scientists engaging in "active participation in state and local decision making"—that is, in deciding the issue in the political arena. In my opinion, their position is fundamentally wrong because it endorses the idea that the contents of a scientific discipline (be it a professional or highly specialized one) can and should be decided politically—that is, by being voted upon by laymen (note that scientists, in principle, are laymen outside their individual fields of expertise).

It may be legitimate to decide by vote whether a curriculum should contain, say, biology, physics, or the Old Testament, but definitely not whether biology should include the evolution of species, physics the theory of relativity, or the Old Testament the Sixth Commandment. As

Frank and Ernest