Time-variation of the fine structure constant and mass-energy conservation.

Abstract

A brief note on the issue of possible time-variation of the fine structure constant \( \alpha_{em} \); it is shown that such a variation should violate mass-energy conservation in the absence of proton decay.

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There has been some recent interest (see for example [1], [2] and [3] and for an excellent review of the subject area [4]) in the possibility of time-variation of the fine structure constant; the coupling of the electromagnetic force.

This brief note is to raise a simple point which seems not to have been noted by previous authors and which has implications for the first law of thermodynamics; one of the most cherished (and most strongly empirically validated) principles in physics.

Currently there is no experimental evidence of proton decay. Whilst this does not prove that the proton is absolutely stable, in the absence of any empirical evidence to the contrary in spite of dedicated searches it is the only assumption that can claim any empirical validity. The same comment applies to the electron.

By the time/Energy uncertainty relation \( \Delta t \Delta E \geq \frac{\hbar}{2} \) we can, theoretically in principle, measure the rest mass of an absolutely stable, and only an absolutely stable, particle to any desired degree of accuracy. (Particles that have a finite lifetime must always have an uncertainty in their mass). Now, in the absence of a complete knowledge of the functional dependence of the masses of the electron and the proton on dynamical factors we cannot pinpoint the exact way in which these masses may vary with a time-varying \( \alpha_{em} \) but, because both carry electromagnetic charge and have electromagnetic self-interaction, we know that the masses in question must have a functional dependence on the value of \( \alpha_{em} \) and should therefore vary if \( \alpha_{em} \) varies. Of course one may hypothesise that, with a time-varying \( \alpha_{em} \), both masses vary in the same way and that the ratio of the masses does not change. That this cannot be the case can be understood from the following. We can express some of the factors (but not necessarily all) which must influence the rest masses of the proton and
electron in terms of the following list of the forces in nature which have an input into the respective mass generation;

\[ M_p; \{\alpha_s, \alpha_{em}, \alpha_w, G_N.\} \text{ and } M_e; \{\alpha_{em}, \alpha_w, G_N.\} \]

i.e. we don’t need a complete knowledge of the origin of the masses in question to assert which of the known forces must make a contribution to the mass. Here \( \alpha_s \) is of course the coupling of the strong interaction and the other couplings are the weak and gravitational interaction. We know empirically that the electron, like other leptons, does not experience the strong force so the \( \alpha_s \) cannot contribute to the electron rest mass.

Therefore in the event of a continuous time-varying \( \alpha_{em} \) there must be a continuous fine-tuning of \( \alpha_s \) or the ratio of rest masses \( M_p/M_e \) will change. Such a continuous fine-tuning is quite untenable since the structural components upon which and through which the two couplings act are quite different; the gluon interaction is quite a different process to electromagnetism and the dynamics of the quark-gluon interaction is quite distinct from the electromagnetic interaction so that the mass components generated by the two different forces will not have any simple functional inter-relationship. Moreover, mechanisms which we might reasonably suppose could account for a time-varying \( \alpha_{em} \) seem inappropriate in the case of the strong interaction; we might, for example (as I think Dirac proposed - or was it in relation the the gravitational constant as well?) consider that the speed of light is some sort of function of the diameter / age of the universe and suppose that \( \alpha_{em} \) varies accordingly? Since electromagnetism is a long-range force perhaps this is a reasonable speculation but it is difficult to see how a parameter such as \( \alpha_s \), which is a short-range force confined in its’ own ‘colour-space’, could conform to such a scheme or any similar scenario. (That the running couplings follow different paths in phase space below the unification scale need not necessarily be an issue here since the measurement in question is that of the rest mass of the proton and electron which, by definition, is the low-energy limit; put another way, the time variation of the couplings at a fixed energy scale and the energy scale variation of the couplings are quite separate issues physically). If any fixed energy scale time variation of \( \alpha_s \) and \( \alpha_{em} \) results from physically independent mechanisms it is inconceivable that the requisite fine-tuning required to maintain a fixed \( M_p/M_e \) should occur.

But then what is wrong with a time-varying \( M_p/M_e \) rest mass ratio? The answer is that, if both these particles are absolutely stable, any variation of the ratio is a violation of mass-energy conservation. Mass simply cannot ‘disappear’ and the first law of thermodynamics remain intact.

It is suggested therefore that, should good empirical evidence be obtained of a time-varying \( \alpha_{em} \), physics must consider dumping the first law of thermodynamics. Alternatively, and possibly more fruitfully, alternative explanations for the empirical observations should be sought. Equivalently it is suggested that, if mass-energy conservation is indeed preserved in the universe, and this certainly seems to be the case empirically, and if the proton and electron are indeed stable then \( \alpha_{em,\frac{2}{c^2}}=0 \) is an invariant of nature. By the same argument \( \alpha_s \) at some fixed energy scale and \( \alpha_w \) must obey the same principle. The gravitational coupling
constant however is not so constrained since it couples to all energy and matter equally thus it is possible $G_N$ may vary in time without variation of the $M_p/M_e$ rest mass ratio.

References

[1] J Webb et. al. astro-ph/0210299 and astro-ph/0210531
[2] H Oberhummer et. al. astro-ph/0210459
[3] A Ivanchik et.al. astro-ph/0210299
[4] J Uzan. hep-ph/0205340 and contained references.