Running of Electromagnetic and Strong Coupling Constants

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Abstract

The observed variation of the electromagnetic coupling constant α, seen in high energy $e^+e^- \rightarrow e^+e^-$ collisions, has been explained in terms of work done compressing the energetic electron. A simple monotonic law has been found, which describes how the electron tries to resist compression, without transmutation. Variation of the strong coupling constant α_S has also been analysed in terms of effective work done compressing the gluon field within a proton's component parts.

PACS: 12.60.-i

Keywords: Running of coupling constants.

Submitted to Journal of Physics G: Nuclear & Particle Physics. 26 October 2010.

1. General Introduction.

It has been observed experimentally that the electromagnetic coupling constant α increases with the squared four-momentum transfer during electron-positron collisions; see TOPAZ Collaboration (1997), L3 Collaboration (2005), OPAL Collaboration (2006) , Mele (2006). This effect has always been explained in terms of vacuum polarization and virtual-loop corrections to the photon propagator, see Gell-Mann & Low (1954), Steinhauser (1998), Jegerlehner (2003). Other experiments have discovered that the strong coupling constant α_s decreases substantially with momentum transfer, for interactions between quarks and gluons within the colliding hadrons; see Bethke, (2000), (2007), and Prosperi et al (2007). Unfortunately, theoretical concepts like renormalisation of singular bare-electrons and negative vacuum energy were invented to establish a quantum field theory which is extraordinarily complex and unnaturally inelegant.

2. Electromagnetic coupling constant ($\alpha = e^2/\hbar c$)

Here in this paper, we shall make use of realistic models of the electron and muon presented in Wayte (2010a, b), (Papers 1, 2), and attribute the running of α to the electron's robust reaction to compression. Paper 1 shows how an electron grows from a small seed during its creation and develops an intricate expanded mechanism in equilibrium. Apparently, this force of expansion can react to oppose the compression which occurs during a subsequent collision process. A simple monotonic law which relates α to momentum transfer is required, in contrast to the adhoc addition of many separate components in electroweak theory. It will be presumed that the electron and positron retain their normal structure throughout an elastic collision, and do not continuously transform into other species as proposed in QED theory

Figure 1 illustrates our proposed theoretical fit of a smooth curve to published data on the running of α, from the L3 collaboration, (2005). The dotted line is for an elementary formula, which will be refined to the solid line. Two QED theoretical values are shown, plus $\alpha^{-1}(m_z^2)$ = 128.936 calculated according to Burkhardt and Pietrzyk (2001). The LEP measurements of α at large momentum transfer lie above the QED prediction by a few percent, giving ($C = 1.05$) rather than 1.0 in the QED formula [$\alpha = \alpha_o/(1-C\Delta\alpha)$].

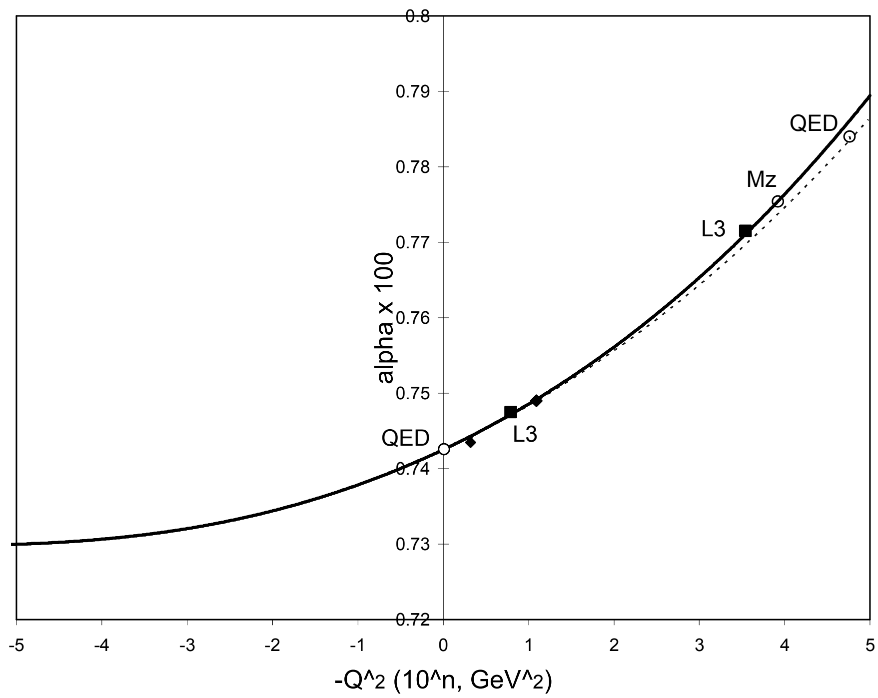

Figure 1. The theoretical variation of alpha with squared momentum transfer. Dotted line shows α_1 from Eq.(2.1); solid line shows the refined value of α from Eq.(2.10). Three hollow markers show QED predictions, and the four solid markers were taken from L3 Collaboration (2005).

2.1 Analysis.

The dotted line in Figure 1 describes α_1 given by the expression:

$$\frac{\alpha_1 - \alpha_o}{\alpha_o} = \frac{\delta\alpha_1}{\alpha_o} = \left[\left(\frac{e_n\alpha_o}{\sqrt{2}}\right)\ln\left(\frac{Q/2 + m_o}{m_o}\right)^2\right]^{(\pi/2)^2} . \tag{2.1}$$

Here $\alpha_o^{-1} = 137.03599968$ is the inverse fine structure constant empirical value, Q represents the total momentum transfer in the $e^+e^- \rightarrow e^+e^-$ process, m_o is the electron or positron rest mass, and $e_n = 2.71828$ is the natural log base. Factors ($\pi/2$) and $\sqrt{2}$ have been used in Papers 1, 2 within *action* equations. By taking logarithms and differentiating Eq.(2.1) we get:

$$\frac{d(\delta\alpha_1)}{(\delta\alpha_1)} \approx \left(\frac{\pi}{2}\right)^2 \times \left[\frac{d\left\{\left(e_n\alpha_o\sqrt{2}\right)\ln[(Q/2+m_o)/m_o]\right\}}{\left\{\left(e_n\alpha_o\sqrt{2}\right)\ln[(Q/2+m_o)/m_o]\right\}}\right] \quad , \qquad (2.2)$$

which has the appearance of a self-normalised equation, employing two main terms on the right-side.

First of all, factor $\ln[(Q/2+m_o)/m_o]$ will be interpreted in terms of work done in compressing the electron, as follows. The most basic action expression for an electron in Paper 1 is:

$$e_o^2 / c = m_o c r_o \quad , \qquad (2.3)$$

where r_o is the classical electron radius and e_o is the constant electronic charge. Electron spin *s* is given by:

$$s = ½\, m_o c r_e = ½\, \hbar \quad , \qquad (2.4)$$

where ($r_e = 137 r_o$) is the Compton radius ($\hbar/m_o c$). When an electron is accelerated by an electric field, it gains kinetic energy but its spin remains constant. Its relativistic mass M_R is therefore contained within a smaller electron spin-loop, and its classical radius is also smaller by the same factor:

$$r_{KE} = e_o^2 / M_R c^2 \, . \qquad (2.5)$$

While the electron is moving freely at high velocity, its charge remains constant at the stationary value e_o .However, during a head-on elastic collision with the positron, the electron is brought to rest with increased *static* rest mass density. This strains its internal mechanism, which causes swelling of the radius above its natural value r_{KE} , and increases the charge above e_o .

Now, the force required to compress an electron core-segment has to act around its circumference against the guidewave creation force, operating as described in Paper 1. It will be put inversely proportional to circumference length but proportional to the electronic charge-squared, therefore:

$$F = ke^2 / 2\pi r \, , \qquad (2.6)$$

where k is a constant. This agrees with the muon analysis in Wayte (Paper 2, Section 4). Work done to compress from original radius r_o to final radius r_{KE} at the metastable rest position is then:

$$W = -\int_{2\pi r_o}^{2\pi r_{KE}} \left(\frac{ke^2}{2\pi r}\right) d(2\pi r) \tag{2.7a}$$

$$\approx ke_o^2 \ln(\frac{r_o}{r_{KE}}) \approx \ ke_o^2 \ln(M_R / m_o) \approx \ ke_o^2 \ln[(Q/2 + m_o)/m_o]\ . \tag{2.7b}$$

Here, M_R is the relativistic mass which has become rest mass temporarily and can be related to the momentum transfer factor for the individual electron or positron, ie. $(M_R \equiv Q/2 + m_o)$. When the electron-positron collision is glancing rather than head-on, M_R is the effective temporary increase in rest mass produced by whatever momentum transfer and slowing of the electron occurs.

The work coefficient $(e_n\alpha_o/\sqrt{2})$ given in Eq.(2.1) needs to be related to *k* in Eq.(2.7), as follows. Let the charge per core-segment be $(e_o/137)$ and the self-interaction potential energy associated with it around the circumference be classically $[E_{CS} = (e_o/137)^2/2\pi r_o]$. Then we will let (ke_o^2) be given by:

$$ke_o^2 = \left(\frac{e_n\alpha_o}{\sqrt{2}}\right)\left[\frac{(e_o/137)^2}{2\pi r_o}\right]\ . \tag{2.8}$$

The compression work done W should then be normalised by standard energy E_{CS} , to satisfy Eq.(2.2). Factor $(e_n\alpha_o/\sqrt{2})$ is effectively a measure of the guidewave compression force relative to the Coulomb force. Factor $\sqrt{2}$ and Eq.(2.6) were discovered for the muon guidewave binding force, (Paper 2); and factor $(e_n\alpha_o)$ was employed for the muon-pearl creation. So these terms are also available here for describing electron compression processes.

The $(\pi/2)^2$ term in Eq.(2.2) has the effect of increasing every element of compression work done, to produce an elemental increase in the fine structure constant. It appears to be caused by the electron's pearls and grains rotating at enhanced velocity $[c' = c(\pi/2)]$, but the underlying mechanism for this is not known.

2.2 Refined analysis.

Given the reasonable success of Eq.(2.1) with the above description of terms, the theory can now be improved. In Eq.(2.7a) the integration for work done should retain variable e^2 because it increases during the integration, $(e^2 = \alpha e_o^2/\alpha_o)$. This has been done numerically by re-introducing the approximate value of α from Eq.(2.1) into Eq.(2.7a) in order to get a more accurate value of W. Then the improved expression for α is:

$$\frac{\alpha-\alpha_o}{\alpha_o}=\frac{\delta\alpha}{\alpha_o}=\left[\left(e_n\alpha_o\sqrt{2}\right)\left(\frac{W}{ke_o^2}\right)\right]^{(\pi/2)^2} \quad . \tag{2.9}$$

This final result for α is shown in Figure1 as the solid curve, and it fits the L3 Collaboration data very well. There is no analytical form which could be related to QED theory, but for comparison with experiment it can be accurately expressed as:

$$\frac{\alpha-\alpha_o}{\alpha_o}=\frac{\delta\alpha}{\alpha_o}=\left\{\tilde{W}_1\left[1-(e_n\alpha_o)\tilde{W}_1+(12e_n\alpha_o)\tilde{W}_1{}^2\right]\right\}^{(\pi/2)^2} \quad , \tag{2.10}$$

where $\tilde{W}_1$ is the normalised work term in the square bracket of Eq.(2.1).

3. Strong coupling constant α_s

A realistic model of the proton, presented in Wayte (2010c), (Paper 3), will be used to help interpret the running of α_s with momentum transfer, in a collision process. Paper 3 shows how a proton mass m_p is composed of 3 trineons (quarks in QCD theory), which consist of 3 pearls each. The mass of a pearl is therefore ($m_\ell = m_p/9 \approx 104.25245$MeV), which is approximately the mass of a muon. Running of α_s is found to be based upon this pearl mass, rather than the proton mass, in a monotonic law.

Figure 2 illustrates our proposed fit of a theoretical curve to published world data on the running of α_s, (Bethke, 2007, and Baldicchi et al, 2007). The line fits data accurately at large momentum transfer, where for example $\alpha_s(M_{Zo}) = 0.11854$, and the latest value for M_{Zo} is 91.1876GeV. This compares well with the empirical world average, $\alpha_s(M_{Zo}) = 0.1189 \pm 0.0010$.

3.1 Analysis

The line in Figure 2 is described by the expression:

$$\alpha_s=1/\left\{\left(\sqrt{2}\ln 2\right)\left[\sqrt{2}\ln\left(\frac{Q'/2+m_\ell}{m_\ell}\right)\right]\right\} \quad . \tag{3.1}$$

Here m_ℓ is the proton's pearl mass, and Q' represents the total momentum transfer Q *plus* $2m_\ell$. Therefore, this numerator includes an extra factor compared with that in Eq.(2.1). Differentiation yields:

$$\frac{d\alpha_S}{\alpha_S} \approx -\frac{d\left\{\sqrt{2}\ln\left[\left(Q'/2+m_\ell\right)/m_\ell\right]\right\}}{\left\{\sqrt{2}\ln\left[\left(Q'/2+m_\ell\right)/m_\ell\right]\right\}}\ , \tag{3.2}$$

which is reminiscent of Eq.(2.2), but is self-normalised with only one main term.

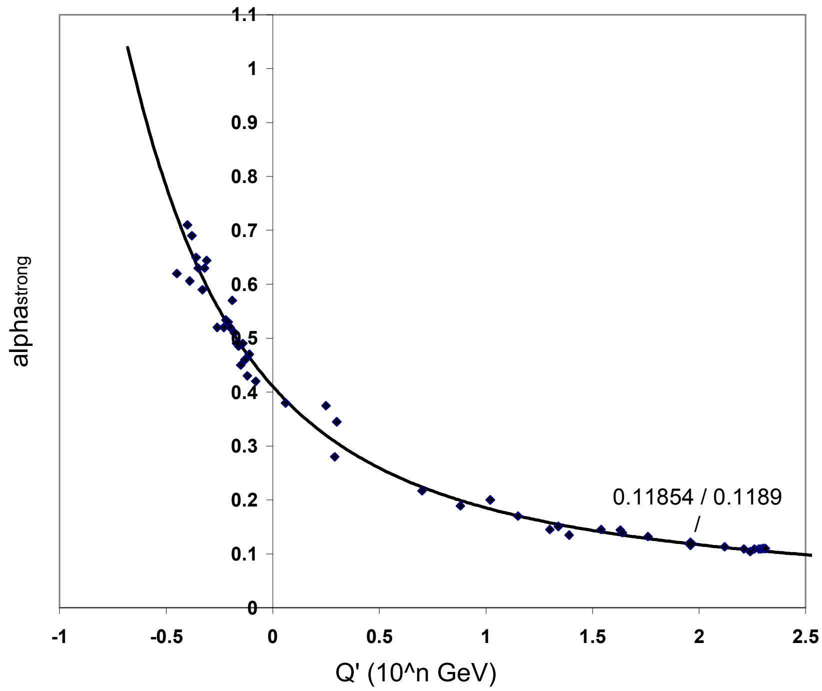

Figure 2. The theoretical variation of α_s with momentum transfer, as calculated from Eq.(3.1), which gives $\alpha_s(M_{Zo})$ = 0.11854. Empirically, $\alpha_s(M_{Zo})$ = 0.1189±0.0010. Data points have been taken from Bethke (2007) Table 1, and Baldicchi et al (2007) Tables 1-7 for Q > 150MeV.

Factor $\{2^{1/2}\mathit{ln}[(Q'/2+m_\ell)/m_\ell]\}$ will now be interpreted in terms of work done in compressing the proton's internal gluon field. First of all, the size of the proton and its pearls are governed by electromagnetic forces. For example, from Paper 3, the proton's *effective* radius is equal to the Compton radius:

$$r_p = \hbar\ /m_pc = 137\ e^2\ /m_pc^2 = 0.2103\text{fm}. \tag{3.3}$$

A trineon's radius is 137(2/π) times smaller, and a pearl is 24 times smaller still. Proton spin is given by:

$$s = ½\, m_p c r_p = ½\hbar \ , \qquad (3.4)$$

and this remains constant when a proton is accelerated by an electric field. Its relativistic mass is therefore contained within a proportionally reduced proton radius, which stays the same when the KE is converted temporarily into rest mass energy during a head-on collision. However, the internal trineons and pearls are also proportionally reduced but are strained to accommodate this temporary high *rest mass* density. This will generate a small increase in the overall electromagnetic charge, as for the electron.

Now the gluon field strength operating around each pearl circumference is also affected by having to accommodate the temporary high rest mass density. Remarkably, the shrinkage of pearl and proton dimensions with relativistic mass increase is accepted by the gluon field like an extended spring being relaxed. Work done is therefore nominally negative potential energy, and α_s decreases as follows. Let the gluon force field acting around a pearl circumference, binding the constituent grains together, be given by:

$$F_g = -\kappa g^2 / 2\pi r \ , \qquad (3.5)$$

where κ is a constant, g^2 is an effective gluon charge squared for the proton, which will empirically evaluate to $\left[g^2/\hbar c = \alpha_s = \left(\sqrt{2}\ln 2\right)^{-2} = 1.0407 \text{ at } \left(Q'/2 = m_\ell\right) \text{ in Eq.(3.1)} \right]$. Work done to compress from an original radius r_ℓ to final radius r_{KE} at the metastable rest position is then approximately:

$$W = \int_{2\pi r_\ell}^{2\pi r_{KE}} \left(\frac{\kappa g^2}{2\pi r} \right) d(2\pi r) = -\kappa g^2 \ln\left(\frac{r_\ell}{r_{KE}} \right) = -\kappa g^2 \ln\left(\frac{m_{KE}}{m_\ell} \right) . \qquad (3.6)$$

Here values of r_{KE} and r_ℓ are inversely proportional to the pearl relativistic mass energy as in Eq.(2.7). And, analogous to Eq.(2.7b), we will let m_{KE} represent ($Q'/2 = Q/2 + m_\ell$).

Now, the extra m_ℓ in the numerator of Eq.(3.1) has to be explained as a residual momentum transfer which remains as $Q \to 0$, and $Q'/2 \to m_\ell$. It will be attributed to the pearl itself having momentum within the trineon which travels around the proton at velocity c. This is like Dirac's electron having internal spin velocity +/− c, as explained in the real electron model of Paper 1. So, even very slow protons in collision will transfer this momentum. Therefore W will be increased to:

$$W = -\kappa g^2 \ln\left[\frac{(Q'/2 + m_\ell}{m_\ell}\right] \quad . \tag{3.7}$$

Finally we will set [$\kappa g^2 = \sqrt{2}(g^2/2\pi r_\ell)$] arbitrarily, then normalise the magnitude of W by a standard energy of self-interaction around the pearl ($g^2/2\pi r_\ell$). Then the main factor in Eq.(3.2) will equal the normalised compression work done:

$$\sqrt{2}\ln\left(\frac{Q'/2 + m_\ell}{m_\ell}\right) = \frac{|W|}{(g^2/2\pi r_\ell)} = \widetilde{W}_S \quad . \tag{3.8}$$

This expression accounts for Eq.(3.1) very well, and the abscissa Q' of Figure 2 is the published value of Q, plus $2m_\ell$.

At first sight, the analysis appears to suggest that only one pearl in a colliding proton conveys the total impact energy/momentum. However, the 9 proton pearls are tied together by an elastic gluon field, which will rapidly equalise momentum transfer throughout.

4. Conclusion

Running of the electromagnetic constant α has been attributed to the action of work done in compressing the electron's internal structure, during a collision process. Apparently, an electron retains its basic design and spin, but shrinks in scale to accommodate its kinetic energy. Only when this KE converts to rest mass in a collision, does the internal stress cause an increase in charge and therefore α. A monotonically increasing power law fits the empirical data very well.

Running of the strong coupling constant α_S has been attributed to the action of effective work done in compressing the internal circumferential gluon field around each pearl in a proton. This occurs when a proton is given kinetic energy which then converts to rest mass energy in a collision process. A monotonically decreasing law fits the empirical data very well.

Aknowledgement

I would like to thank Imperial College Libraries, and Lu Gao for typing.

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