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The Plum–Pudding Model of Hadrons

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The Thompsons plum-pudding model of the atom, now of historical interest is well-known. In this note we point out that the Thompson's plum-pudding model might explain the behaviour of quarks inside hadrons.

Thompson assumed that the electron in the hydrogen atom is a negatively charged point-like object embeded in the proton whose charge is uniformly distributed over a sphere of radius $r_o \sim 1$ fermi. An extremely simple calculation shows that the force acting on the electron when it is displaced a distance r from the centre of the nucleus is $-re^2\hat{r}/r_o^3$ (where $\hat{r}$ is the unit vector in the radial direction). Thus the motion of the electron is simple harmonic and the frequency of oscillation is given by,

$$\omega = (e^2/r_o^3 m)^{1/2} \quad . \qquad (1)$$

Now we know that large number of experimental facts tends to indicate that the nucleon has point-like constituents (quarks). The quarks are also supposed to be associated with a massless vector field[1] (colour gluon field). The nucleon as a whole is neutral with respect to the colour charge. Thus when the quarks are displaced from the central region of the nucleon they are expected to be subjected to forces of the type proposed by Thompson. If g is coupling constant of quarks and colour gluons and m is the quark mass, the frequency of oscillation of a quark inside the nucleon is given by (1) with e replaced by g. Quantizing oscillations, the quark energy can be written in the form,

$$E = (n + 3/2)\ h\ (g^2/r_o^3 m), \qquad (2)$$

where $n = 0, 1, 2 \ldots\ldots\ldots$

Since the nucleon radius $r_0 \simeq h/m_\pi c$, the Compton wave length of the pion, the above expression can be written in the form,

$$E = m_\pi\ (g^2/hc)\ (m_\pi/m)\ (n + 3/2), \qquad (3)$$

where g^2/hc is the dimensionless quark-colour gluon coupling constant. Assuming that $g^2/hc \sim 1$ (same order of magnitude as the strong interaction coupling constant) and $m \sim m_n/3$ (most quark models favour u and d quarks having masses of the order 1/3 nucleon mass[2]), from (3) we get a spacing between energy levels of the order 50 MeV. The harmonic oscillator model[2] of baryon resonances needs a spacing levels of the above order of magnitude. However these models do not explain the origin of the harmonic oscillator forces that bind quarks. The model we have presented here explains the origin of such forces.

This model is also interesting in another aspect. It is known that in nucleon collisions, the excited nucleon, dexcite itself by fragmentation into mesons. It is possible that this is caused by quark oscillations within the nucleon, analogous to mechanism proposed for light emission in the Thompson model of the atom.

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