The consequences for the electron of a proposed variation of the gravity constant with time

If the strength of gravity decreases with time then it can be shown that the electron could be a quantum black hole, and this introduces a possible new derived constant of nature. These results are developed to reveal that for the electron, rest mass energy, spin energy and electrical energy are all equivalent under these premises, and precisely opposed to gravitational self-energy. Also that the rest mass energy of the electron is essentially the kinetic energy of its spin. Lastly, electric charge is expressed in gravitational terms.

W.M.M. January 1999

A new natural constant

Assuming that gravity has weakened over time, what could we infer from this? First, gravity in the past would have been stronger. Possibly very much stronger. Let us assume that the process has always gone on and that it is not just a fluctuating or intermittent effect of something local but quite outside our experience.[1] It is reasonable to extrapolate and suggest that in the limit of zero time, gravity could have been infinitely strong or at least extremely large.[2]

Enough to say that at some early moment after t = 0 it would surely have been as strong as the electromagnetic field we know today. This lets us write an equation for two masses carrying like net charge, such that the gravitational force between them then, was exactly equal but opposite to the electrical repulsion we see between an equivalent pair today. We might call this a zero energy equation because integrating these relations gives negative gravitational energy, but positive electrical energy and such an equation sums to zero.

So saying, as one resource we have Newton's gravitational law[3];

$F = Gm_1m_2/r^2$

where F is a force, m_n is an arbitrary mass and r is an arbitrary separation between the masses. We will assume that this law holds for all values of r and that it remains true for very strong fields, provided we can treat the participating masses as pointlike. This is an artificial condition, it is true, but for the moment we are generalising and we are not concerned with specific objects.

We also have Coulomb's law for electrostatic charges[4];

$F = \gamma q_1q_2/r^2$

where γ is the electrostatic constant[5] such that

$\gamma = 8.9875543 \times 10^9 \ Nm^2C^{-2}$

and q_n is some arbitrary charge. We will also make the proviso that the law is valid for small r provided the charges are pointlike.

Now, by adjusting G, m and q we can construct a condition for which the gravitational attraction in the past exactly balances the electrostatic repulsion today at all distances r for pointlike objects. We can describe this by

$G \, m_1m_2/r^2 = -\gamma q_1q_2/r^2$

Note the use of a negative sign to denote repulsion. Integrating will give an equation between energies, and these will sum to zero.

Now consider that the smallest free particle of electrically charged matter in our universe is the electron. Put the values for the electron's charge and mass into the equation. In terms of modern G of course the equation immediately breaks down[6]. The gravitational side is far too small by the enormous factor of 10^{42}.

However, if G has declined with time, let us take our mind experiment right back to a moment when G was big enough to render the above equation correct for two electrons. As if they were experiencing no nett force, assuming that back then they carried what we know as electric charge today. Of course we have to be careful to understand that this equation is not meant to imply that two electrons then actually did experience no nett force between them.

Certainly gravity existed, and may have been immensely strong under the premise of this opus, but we cannot assume that electrical field even existed at that stage. Instead we should regard it as a comparison of the gravitational attraction then, compared to the electrical repulsion now. Obviously it is logically inevitable that given a continually declining value for G from an infinite or exceedingly large value at the instant of the creative singularity, then there had to have been such a time in the past when the above equation would make sense when appropriately interpreted.

To do this G must be expanded so that the expression

$G_em_e^2 = -\gamma e^2$

is quantitatively true, albeit that at first sight it looks like a dimensional monstrosity[7]. In fact it is not but that isn't apparent yet. Also since the charge and mass reside on the same body, this relation is independent of the distance of separation and the r term can be dropped. The problem of pointlike sources is now resolved because we are not dealing with forces after all, but some kind of deeper connection between the gravitational and electrical nature of the electron itself.

The charge e is that of the electron,

$e = 1.6021917 \times 10^{-19}$ C

The electron mass is

$m_e = 9.109558 \times 10^{-31}$ kg

and G_e is a true constant such that

$G_e = 2.780165 \times 10^{32}\ Nm^2kg^{-2}$

Thus we can offer as a definition

$G_e = \gamma e^2/m_e^2$

Being a constant made up of signless terms, it is justifiable to ignore the vector sense and eliminate the negative sign for this purpose.

But there is another fundamental natural constant, the *fine structure constant*[8], α, such that

$\alpha = \gamma e^2/\hbar c$

$\quad = 7.297351 \times 10^{-3}$ (no units)

where c is the velocity of light in vacuo, $2.9979250\ ms^{-1}$, and $\hbar$ is the short (Dirac) form[9] of Planck's constant h. Quantitatively,

$h = 6.626196 \times 10^{-34}$ Js and

$\hbar = h/2\pi$
$\quad = 1.054592 \times 10^{-34}$ Js

The fine structure constant itself is dimensionless, as can be seen from its units because dimensionally $[\gamma e^2] = [ML^3T^{-2}]$ from the force law, but $\hbar c$ has the same dimensions. It acts as a scaling factor, and among other properties it provides a benchmark for the strength of the electromagnetic field. It follows that

$\gamma e^2 = \hbar c\alpha$

and therefore that

$G_e = \hbar c\alpha/m_e^2$

This is a much better definition of G_e because it uses fundamental rather than derived constants. As such it can be seen to be the statement of a true constant of nature, and it is vital to the exposition that follows. Please take careful note of it and that the apparent dimensional clash mentioned above is resolved. The constant γ can be justifiably treated as dimensionless so the above dimensions are those of e^2. More to the point, it is a very strong indicator that G is a true variable, otherwise how could there be two G values?

Dimensional analysis shows that G and G_e are both the same kind of object. So, G_e is a valid version of G and it suggests that G is not constant. Though it is the value of G when the gravitati0nal field was as strong as the electric field is today, G_e is not itself a variable. We can thus use it as a constant wherever it logically applies in any equation that is numerically and dimensionally valid.

References and notes;

1. Obviously we do not know everything about the universe, and it cannot be discounted that there might be irregularities in the geometry of space. One obvious one is the presence of random lumps of matter, but we understand this reasonably well. Less obvious is the 'dark matter' that is now believed to be distributed throughout space, and this might be some exotic form that behaves in a different way gravitationally.

   Nevertheless, despite such speculations, for the present we are advised by consideration of Occam's razor to stay with what we know. This behooves us to make only the one speculation that G decreases with time, and to assume that it does so smoothly according to some simple reductionist law.

   An informative and authoritative modern work is;
   D.W. Sciama; "Modern cosmology and the dark matter problem", Cambridge University Press, 1993.

2. The Big Bang model of universal creation mathematically generates a singularity at t = 0 (Hawking 1970). This suggests initial infinite densities, pressures and temperatures. Also the curvature of space would be infinitely rolled up into a point and gravitation itself would be infinite. It is very hard to see how such an object could ever expand at all!

   Indeed, nature seems to abhor singularities, and where they appear they seem to be telling us that there is something missing from our theory. For example, Bohr's model of the atom contained a singularity at the atomic nucleus. Orbiting electrons should radiate energy and spiral into the nucleus, but they obviously don't.

   In that case the impasse was broken by the quantum shell model. So what allows the universe to avoid the singularity at t = 0? It is the Heisenberg uncertainty principle (Born and Heisenberg, 1927);

   $\Delta E \, \Delta T = \hbar$

   where here E would be Mc^2, M being the mass of the universe (around 10^{50} tonnes) and T would be an exceedingly small time (in the order of 10^{-105} seconds) during which nothing could be defined, not even the total mass of the universe.

It allows M to grow from some pre-existent state (albeit unknown) rather than seeming to just pop into existence instantaneously, and for pressure and temperature to develop from an initial state that is less vigorous. By the time ΔT has elapsed, all these factors, and presumably G as well, are defined, very large but finite, and the singularity is circumvented. See

Stephen Hawking and Roger Penrose; "The nature of space and time", Princeton University Press, c1996.

S.W. Hawking; "A Brief History of Time", 1988

3. A recent appraisal of Newton's classical theory from a biographical viewpoint is

   Steve Parker; "Isaac Newton and gravity", Chelsea House, 1995.

   Newton wrote in Latin, but the earliest English translation was

   Sir Isaac Newton; "The mathematical principles of natural philosophy", translated into English by Andrew Motte. To which is added,

   John Machin; "The laws of the moon's motion according to gravity", 1729

4. The classical publication of Coulomb's experiment was

   Coulomb C.A.; Memoirs of the French Royal Academy of Sciences, 1785 - 89.

   Two useful modern presentations are

   Warren B. Cheston; "Elementary theory of electric and magnetic fields", Wiley, 1964.

   S. W. Hockey; "Fundamental electrostatics", Methuen, 1972

5. Values of all the constants used in this opus were taken from Encyclopedia Britannica 1978, Macropedia volume 5, "Physical Constants".

   However the electrostatic (Coulomb) constant γ is treated rather differently from the others. Although it was originally a measured constant like any other, subsequently in the light of its measure, the electrical unit system was adjusted to render it easier to measure by considering its connection to the Maxwell equation

   $\varepsilon_0\mu_0 = 1/c^2$

   where ε_0 is the permittivity of free space, μ_0 is the magnetic permeability of free space and c is the speed of light in vacuo.

The adjustment was to render the permeability constant divided by 4π equal to 10^{-7} webers per amp metre *precisely*. This in turn called for slight modifications to other familiar electrical units, such as the volt, amp and ohm, and of course the Coulomb constant which can be derived from the permittivity constant by the equation

$\gamma = 1 / (4\pi\varepsilon_0)$

The reason for this adjustment is that we can measure magnetic fields in the laboratory with great precision, and we can then use the Maxwell equations to derive everything else, whereas getting a good measure of γ directly is fraught with difficulty because electrons are so slippery. Holding and maintaining a static charge on anything long enough to take accurate readings is very difficult indeed.

The permittivity constant is thus a calculated constant, as too is the Coulomb constant γ. If we have got it right then, using our new units, the measured and calculated value of γ should be equal to within the limits of experimental accuracy so in fundamental terms nothing has really altered except the units we use.

It should be realised though that in terms of physical reality, electric charge cannot be separated from the electrostatic constant, or more particularly from the permittivity constant in any electrical discussion. Charge without a consideration of its ability to create a field means very little.

To get around this and make calculations more convenient, electrodynamic considerations are often expressed using the esu system of units which reduce the electrostatic constant to unity, and it also has to be regarded as dimensionless.

Although this is a useful method, in fact the assumption is not entirely justified by a deeper consideration of the electric field. All that can be said is that it works, so the assumption appears to be true, but if this is so then the permeability constant is not dimensionless, and has the dimensions of inverse velocity $[L^{-2}T^{2}]$ from the Maxwell equation (see note 5 below for more on dimensions.) This itself is actually very reasonable given that magnetic field only arise from *moving* charges, and the field strength depends entirely on the velocity of the current.

This problem of the ephemeral nature of charge seems to reflect the fact that we cannot extract a charge from any system without carrying a mass along with it. Isolated charge simply does not exist in any physical sense and only has meaning in terms of the field it generates and the mass on which it resides.

The magnetic situation is even worse. Despite the fact that the Maxwell equations do not forbid them, no magnetic particles as such appear to exist at all. All searches for the postulated 'magnetic monopole' have been fruitless.

In magnetic field considerations, there is no magnetic charge as such, and it can only be defined in terms of the permeability constant and a moving charge. Since there is no limit to how slowly an electron might move, there is no general physical quantum of magnetism separable from the electron charge.

For further reading on general electrodynamics, a good source is

A.F. Kip; "Fundamentals of Electricity and Magnetism" 2nd edition, 1969.

6. Modern gravity is a very weak force. This is not apparent as we are used to the force exerted by a very large object, the earth. The weakness of gravity however makes it very difficult to measure G. The basic method of measuring the strength of gravity (and thus the value of G) is to use a Cavendish balance. This essentially consists of two large masses suspended by a long torsion spring, in the past, drawn quartz fibre. More recently optical fibre has been used for this purpose as its properties along a length are more constant than quartz.

   The two masses are arranged to attract each other gravitationally and the deflection of the torsion fibre noted by using a laser reflected in a mirror attached to it. The trouble is that the masses are limited (or the fibre would break) and the force is very minute.

   The whole apparatus needs to be insulated from ground vibration, large unbalanced masses in the vicinity such as a nearby mountain range, atmospheric draughts and temperature changes. The best place to do this kind of experiment would be down a mine shaft in a tectonically stable location without nearby mountains or mineral masses, with a very long suspension fibre and remote control, because even the proximity of a human body can upset the readings.

   The classical publication on this topic is;

   Henry Cavendish; "Experiments to Determine the Density of the Earth", Philosophical Transactions of the Royal Society, 88:468-527, 1798.

   A modern contribution is

   R.D Rose et al; "Determination of the Gravitational Constant G", Physical review letters, 23:665-658, 1969.

7. Dimensional analysis is used to check the validity of arguments in dynamical problems. The method is to reduce all equations to their 'dimensions', that is, the fundamental elements of mass, length and time that make them up. Thus for example kinetic energy $E = ½mv^2$ reduces to $[M L^2 T^{-2}]$ but so too gravitational potential $E = m g h$ also reduces to the same dimensions.

   This indicates that both are energy and are interchangeable. Problems arise however when charge is introduced into the situation. From the dimensions of force, and regarding γ as dimensionless, the dimensions of charge are sometimes quoted as $[M^{1/2} L^{3/2} T^{-1}]$ but there is no real theoretical justification for treating γ as dimensionless.

Notwithstanding, it works. Sometimes the problem is hedged by just introducing another dimension Q, then the dimensions of γ are $[ML^3T^{-2}Q^{-2}]$ and this solves the problem up to a point. The trouble is of course that fundamentally nobody knows what charge actually is, so its real relation to M, L and T is unknown.

A useful treatise on dimensional analysis is

H.E. Huntley; "Dimensional Analysis", 1952.

8. The fine structure constant got its name because it was first recognised by spectroscopists who detected the hyperfine splitting of spectral lines due to the internal properties of electron orbitals in atoms. In due course it was found to operate ubiquitously over the whole of electrodynamics. Some of its consequences are i) it acts as a scaling factor that determines the strength of the electromagnetic field. ii) it sets the size of the electromagnetic electron. iii) it sets the radius of the lowest energy level in a hydrogen atom.

   Exactly what the fine structure constant is however rather enigmatic but it seems to be a true scaling factor that maps the quantum world onto the more familiar electromagnetic structure of existence. In particular it determines the size and intensity of many physical processes involving the electromagnetic field. For a good historical perspective see;

   E.R Cohen, K.M. Crowe, J.W.M. Dumond; "The Fundamental Constants of Physics, 1957.

9. The classical description of Planck's constant can be found in

   Max Planck; "Original papers in quantum physics" annotated by Hans Kangro, translated by D. ter Haar and Stephen G. Brush, London, Taylor & Francis; New York, Halsted Press Division Wiley, 1972.

   Another very thorough introduction to quantum theory is

   W. Heitler, "The Quantum Theory of Radiation’, 3rd edition, 1964.

   The variant of Planck's constant is described in

   P.A.M. Dirac; "The principles of quantum mechanics", 4th edition, Clarendon Press, 1958.