

The Nature of Electric Charge

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We have completed our appraisal of the electron as a massive body, but we know it has another property we have not yet addressed in any detail. The electron is the fundamental unit of electricity. But what *is* electricity? The name covers a wide range of phenomena, and though it serves us as our most important source of energy, we really don't know what it is. We do know a great deal about what it *does* however. In general, the term 'electricity' refers to any process involving the activities of entities carrying electric charge. The problem stems from the fact that we really have no idea what charge actually is, or how it comes about. So saying we should rephrase the question. What is *electric charge*?

Let's consider what we have. Matter is made up of positive and negative charges. The negative charges reside on electrons, which if the premise of variable G is correct, we have now identified as having been formed as quantum black holes just after the big bang when G was $\hbar c \alpha / m_e^2$. Positive charges in normal matter reside on protons, with a mass 1836.109 times that of an electron, but these are not the lightest known objects carrying positive charge. It would seem that the elementary positive charge is in fact the positron, the antiparticle of the electron, even though the positron is not stable in company with normal matter.

First consider that at some short time after the big bang, a piece of energy wrapped an event horizon around itself, and became the first electron. It was a quantum black hole. General relativity tells us though that from the viewpoint of an outside observer *time does not run at the surface of a black hole*,¹ so time did not run thereafter at the surface of the new electron. This means of course that even today the surface of an electron from our point of view has not progressed in time one jot past the moment of its creation.

Of importance though, to any electron, any *other* electron is similarly frozen in time. Each electron is also seen by another as still being at the moment of its creation, a mere split second after the big bang. This doesn't mean that we can't watch electrons move about in our own frame of reference; a wholly time oriented behaviour. The point is however that they aren't doing it in *their* time. They are doing it in ours, and that's why we have to see that all-important force called electricity.

The reason for this is actually surprisingly obvious when we realise how nature compensates for viewing a force in one reference frame from another. It generates a new force.²

At the moment of creation of the electron, if one interacted with another, they

would be under a colossal mutual tension for two objects of such a small size, simply because gravity was so immensely strong at the time. In fact the force between two electrons in contact under this regime would be nearly three-quarters of a kilogram of weight! This might not sound much, but scale for scale it is the equivalent of a human being weighing around 10^{30} tonnes.

The salient point though, is that if two electrons meet *today*, exactly the same thing necessarily happens *in their own reference frame* for they are still suspended in that moment. But, you say, this will not do. Obviously when two electrons meet they repel each other with great vigour. Yes, this is true - in *our* frame of reference. But we know that when we are faced with a force in two conflicting frames of reference, we have to introduce a transformation and the result is inevitably a new force that corrects the dilemma.

Einstein showed us how the different reference frames of moving charges introduce the relativistic transformation that gives us the magnetic field. Could something similar be going on here? Consider the numbers. Two electrons in contact pull each other with a force of 7.24 Newtons in their own reference frame, and 1.75×10^{-42} Newtons in our frame. The ratio of these is just G_e/G , or 4.14×10^{42} . It is also the ratio of γe^2 to $G m_e^2$

In essence, in order for us to be able to accept that the two electrons only feel a very feeble gravity pull, we have to observe a force that acts to resist the huge pull as seen by the electrons themselves, otherwise what we see would not make sense. This has to be in the order of 10^{42} times stronger than modern gravity.

We call this electrostatic force, and it pushes the other way. Considered in this manner, the transformation is actually very simple. Ignoring the minute contribution to the total force by the modern gravitational interaction, to a first order of accuracy the ancient gravitational force F_{Ge} can be regarded as being entirely countered by the electrostatic force.

Call this F_γ , and we will say that

$$F_{Ge} + F_\gamma = 0 \quad \text{so}$$

$$F_{Ge} = -F_\gamma \quad \text{and}$$

$$-F_\gamma = F_G G_e/G$$

(where F_G is the force of modern gravity) because the electrostatic force is 10^{42} times the force of modern gravity, in the same ratio as ancient to modern gravity. This is the transformation, and it is indeed extremely simple.

So

$$-GF_\gamma = G_e F_G \quad \text{or}$$

$$-G\gamma e^2 = G_e G m_e^2$$

which is just our original proposition that $-\gamma e^2 = G_e m_e^2$. Since we have defined this to be a true statement under the terms of this work, the original proposition that

$$-F_\gamma = F_G G_e / G$$

is also true. The negative sign just identifies the electrical force vector as a repulsion. Charge itself then appears as a consequence of the physics of the situation to provide a source of this force.

Force is an *interaction*, so observed reality demands that a force needs some focal basis to make sense. Something has to *apply* the force. All simple fields have some kind of centre and need some definable source. Even a cyclical field like magnetism calls upon us to assign focal sources just to be able to work with it mathematically. In the analytic treatment of magnetic influences between currents we have to invent 'current elements' to act as individual ad hoc sources for the field just in order to have equations that make sense. Also in a permanent magnet - which is actually a collection of many very small current loops - we find that the field tends toward two abstract points within the magnet that we call north and south poles.

So, let's consider charge as an abstract parameter that gives us a measurable factor that we can treat as the source of an electrical field. This is easily stated given that

$$e^2 / 4\pi\epsilon_0 = G_e m_e^2 \quad \text{so}$$

$$e^2 = 4\pi\epsilon_0 G_e m_e^2$$

$$e = \pm 2m_e \sqrt{\pi\epsilon_0 G_e}$$

$$e = \pm 2m_e \sqrt{\pi\epsilon_0 \hbar c \alpha} / m_e^2$$

$$e = \pm 2\sqrt{\pi\epsilon_0 \hbar c \alpha}$$

Note that the mathematics of this automatically tells us to expect two types of charge.

The above equations provide what we wanted, namely a statement of focus for electric charge in gravitational terms but it does not segregate e from the essentially electrical constant ϵ_0 . Of course e and ϵ_0 can never be isolated from each other in principle. Charge gives us a source for electrical energy, but alone it cannot tell us what to expect in the way of a field. It is after all only the field which is real. It is the field that applies force, not the charge. Or we could look at it another way and say that there has to be a factor describing how well a charge does its job, and permittivity gives us this. It would be better therefore to treat $e/\sqrt{\epsilon_0}$ as the parameter of concern, so

$$e/\sqrt{\epsilon_0} = \pm 2\sqrt{\pi G_e m_e^2}$$

This inseparability has been recognised for a long time and regarded as something of a nuisance because one had to lug this object $\gamma = 1/4\pi\epsilon_0$ around all the

time, but it never did anything mathematically. This inconvenience was solved by the invention of the electrostatic units. These are just the ordinary electrical units quantitatively adjusted to reduce the constant γ to unity, and this is made acceptable by regarding γ as dimensionless. It can be done by regarding the magnetic permeability constant μ_0 as having the same dimensions as $1/c^2$ from the Maxwell equation $\mu_0\epsilon_0 = 1/c^2$.

When this is done, the electron charge can be written

$$e = \pm\sqrt{G_e m_e^2}$$

This seems to tell us that electrostatic force is indeed just a reflection of the ancient gravity of space when the electron came into being. But there are some problems. If electrostatic force is just a compensating force for ancient gravity, it suggests that in earlier times when G was bigger, F_γ would necessarily have been weaker. Surely then atomic matter would have been severely affected?

One has visions of bloated atoms taking part in unimaginable chemistries in a universe so alien as to be quite unacceptable as our own and we know this never happened. After all, we can *see* ancient galaxies, and even analyse their chemical composition, and allowing for redshift, they are as 'normal' as our own galaxy. They are just far away and younger than our own. If this hypothesis is to make sense, we must deal with this apparent problem.

So saying, consider that today we do not include gravity in atomic theory only because it is so weak that it is insignificant. In truth, the correct expression for the interaction between an electron and a proton is

$$F = F_\gamma + F_G$$

Expanding,

$$F = \gamma e^2/r^2 + G m_e m_p/r^2$$

Where m_p is the mass of the proton, but the second term is far too small to matter. In fact, if G were to be made large so the term becomes significant, in order to preserve chemistry we would have to say that

$$\gamma e^2 + G m_e m_p = k$$

and this constant k should extend not only to atoms, but to *all* elementary charge couples.

Consider an electron-positron pair. Now, although such a pair is very unstable because at some stage its members will meet, a quasi-stable state called positronium exists in which an electron and a positron combine to produce a type of lightweight short lived atom. The above relation would then be

$$\gamma e^2 + G m_e^2 = k$$

(same k) and stepping back through time, in the limit this would be

$$\gamma e^2 + G_e m_e^2 = k$$

when of course the electrical term would reduce to zero. In fact

$$k = G_e m_e^2 \quad \text{so}$$

$$\gamma e^2 + G m_e^2 = G_e m_e^2 \quad \text{and}$$

$$\gamma e^2 = m_e^2 (G_e - G) \quad \text{or}$$

$$e^2 / 4\pi\epsilon_0 = m_e^2 (G_e - G)$$

$$e / \sqrt{\epsilon_0} = \pm 2m_e \sqrt{\pi(G_e - G)}$$

Do not try combining the two equations we now have for $e/\sqrt{\epsilon_0}$. They are not given in the same context. The first looks at the ideal charge on the electron if we ignore the contribution of modern gravity to the total interaction. The astute reader will surely by now have realised that this proposal requires e itself to be a variable. More on this in a moment. In fact though, the first expression gives the value of $e/\sqrt{\epsilon_0}$ at the end of time, when gravity has declined to zero. It thus expresses an abstract limit, the maximum value of charge that an electron will ever have. The second expression is actually the correct one for the present day, for it does take modern gravity into account and thus gives the true value of the electron charge today, and for any time since creation, and any reasonable time into the future.

In passing, please note that the difference between these two values is actually vastly below the limits of our capacity to measure. This exposition is purely theoretical. In practical terms we would of course never bother to include the gravitational term. Likewise, there is no need to ever concern ourselves with charge as a variable. We are never going to have to consider it in any practical application, albeit that it may be possible to detect the change indirectly by means of a sufficiently sensitive method.

Nevertheless, according to the argument here the change must happen. Either ϵ_0 must decrease, or e must increase with time since G_e and m_e are constant. But if ϵ_0 alters, this does enormous violence to theory right across the board. It is much safer to regard e as the variable quantity. Then to preserve the constancy of such quantities as the fine structure constant and the Compton wavelength, wherever γe^2 appears, it is replaced with the complete form $\gamma e^2 + G m_e^2$. This works well, but there is still a problem.

The equation $\gamma e^2 = m_e^2 (G_e - G)$ actually seems to compromise the initial premise of this thesis. When G was G_e , e disappears entirely, so how can we say that when G was G_e , that the foundational statement $\gamma e^2 = G_e m_e^2$ was true? Simply - we don't. We aren't describing the same situation. The latter equation provides a quantification for G when it provided a gravity field as strong as the electrostatic field is *today*. It does *not* address the question of whether or not charge as such existed *then*.

The equation $\gamma e^2 = m_e^2 (G_e - G)$ *does*, and it says that back then, G was G_e and charge as we understand it did *not* exist. Not that an atom could not have theoretically

existed then if all its components were available. It just means that the electrons would have orbited under purely gravitational forces. But of course an atom might not have existed then for another reason. The proton and neutron as yet had probably not been invented.

However, as soon as the electron appeared, G continued to decline precipitously³, charge became defined and increased rapidly, and all interactions with electrons involved the relation

$$F = (\gamma_e Q + G m_e M) / r^2$$

where Q and M are the charge and mass of anything else, G could have any value less than G_e and γ_e is a combined term comprising the extant charge on the electron at the time, and the permittivity of space. In due course atoms were created, and perhaps at first the gravitational factor had a small significance in their overall structure - albeit by the time complete atoms appeared G had probably fallen almost to its modern value. Thereafter it was just too small to have any discernable effect, and the electrical factor took over completely for all practical purposes.

Chemistry was never compromised at any stage. Nor was anything else. The overall interaction was conserved at all times. Even the quantum mechanical structure of atomic energy levels would be the same because everywhere that $G_e m_e^2$ appears in a quantum statement, γ_e^2 simply takes its place. *Electromagnetic quantum mechanics, and gravitational quantum mechanics are therefore essentially the same!* The thing that has so far fooled everyone with respect to gravitational quantum theory is that if G has shrunk, then any modern quantisation of gravity as we observe it today has become insignificant to any description of reality! Any attempt to build a meaningful quantum theory based on modern gravity is doomed to fail.

When charge was small, gravity was strong, and electromagnetism was extremely weak, but a field that Robert L. Forward once dubbed informally 'graviprotation' stood in for it. What is graviprotation? Basically, gravitational radiation³. This comes about because of *gravitational magnetism* or 'protation'. When masses move, there is the same discrepancy produced for gravity as occurs for the electrostatic field when charges move. Furthermore, when masses accelerate, a process analogous to the production of light occurs. Gravitational field couples with protational field to generate extremely weak (today) *gravity waves* or gravitational radiation. Using Forward's terminology then, *graviprotation* is analogous to electromagnetism. But we aren't out of the woods entirely even yet.

We have generated a special case in which the charge of an electron can be described in gravitational terms, but it must be said that we have not yet solved the charge couple problem entirely. It works for a positronium atom, in which we are dealing only with electrons - the positron being regarded as just a positively charged electron - but it does not necessarily extend to real atoms. Nor can we claim anything like a general principle.

So saying, we shall now attempt to generalise the charge equation to incorporate other elementary particles, in particular the proton, which will allow us to make inferences regarding charge in all real matter. Consider first the force between

an electron and a proton when we compare the frame of reference of the electron with our own. *To the electron* there is a force of

$$F = G_e m_e m_p / r^2$$

Acting between them. What we see is

$$F = \gamma e^2 + G m_e m_p / r^2$$

By the same reasoning as we used for the positronium atom

$$\gamma e^2 + G m_e m_p = G_e m_e m_p$$

Now do the same thing for this pair again, but compare our view with that of the proton. Here we meet a problem. We don't quite know the status of a proton. Does it see charge as we do, or does it see it under some enhancement of gravity? If it is a black hole we have no problem. We have a value of G , call it G_p , that can stand in for G_e . We can in fact use the same reasoning that revealed the electron as a black hole, and come up with what looks like a black hole model of the proton.

The gravity term G_p however has no special significance in terms of the other constants without the application of the proton/electron mass ratio Q . This of course destroys any independence of the derivation. As we do not know the significance of Q the whole argument is not very useful. In fact, in the case of the proton, the black hole model may just be an artefact as there are some quite severe aspects militating against it. For one thing, though there are lighter particles with the same charge and spin (the positrons) protons do not decay by the Hawking mechanism or any other.

Furthermore, unlike the electron, it is possible with scattering experiments to discern a size for the proton. Though small, it is not pointlike, and furthermore it does not appear to have altered in size at any time throughout history. So, let's hedge and just say that there is a value of G we will call G_p that the proton sees (and it just might be modern G) and allow it to act as a dummy variable. This is safe because as will be seen, it disappears from the final form anyway.

We get

$$\gamma e^2 + G m_e m_p = G_p m_e m_p$$

where G_p is the gravity factor that the proton experiences, whatever that might be. Let's also add another couple to this set, an entity like a positronium atom, but extremely short lived, a protonium atom; a proton/antiproton couple. Not forbidden, just *very* unstable. Here the two protons see a force governed by G_p so that

$$\gamma e^2 + G m_p^2 = G_p m_p^2$$

If we now resolve these for γe^2 it becomes readily obvious that none of the four examples so far considered can be equated with each other. The entities see different forces because they operate in different reference frames. The factor γe^2 works out different in each case, and this will not do, because *we* have to see it to be the same in

every case. Obviously our treatment has been a little too simplistic. We can however resolve and generalise the overall transformation. First resolve all four cases to simplest terms.

Including the positronium case we get

$$1) \gamma e^2 = m_e^2(G_e - G)$$

$$2) \gamma e^2 = m_e m_p(G_e - G)$$

$$3) \gamma e^2 = m_e m_p(G_p - G)$$

$$4) \gamma e^2 = m_p^2(G_p - G)$$

Now do a pairwise comparison of each of 2,3 and 4 with 1, applying a factor in each case that makes the equation true;

$$1,2) m_e^2(G_e - G) = B m_e m_p(G_e - G)$$

$$1,3) m_e^2(G_e - G) = C m_e m_p(G_p - G)$$

$$1,4) m_e^2(G_e - G) = D m_p m_p(G_p - G)$$

and resolve for B, C and D, but do not cancel the bracketed terms in 1,2.

We find that

$$B = (m_e/m_p) (G_e - G) / (G_e - G)$$

$$C = (m_e/m_p) (G_e - G) / (G_p - G)$$

$$D = (m_e/m_p)^2 (G_e - G) / (G_p - G)$$

Next, fiddle with the electron/positron example and say that it has a factor as well, but that it is the unitary equation

$$A = (m_e/m_p)^0 (G_e - G) / (G_e - G)$$

and rewrite B and C with explicit unit powers of (m_e/m_p) . Don't worry for the moment that we have introduced the proton into an electron/positron situation. We could just as well have introduced cabbages for that matter, provided the overall expression was unitary.

We can now substitute these to generalise the equations above by saying that for two electrons; $\gamma e^2 = (m_e/m_p)^0 (m_e m_p)(G_e - G)(G_e - G)/(G_e - G)$

and for an electron in a proton field;

$$\gamma e^2 = (m_e/m_p)^1 (m_e m_p)(G_e - G)(G_e - G)/(G_e - G)$$

and for a proton in an electron's field;

$$\gamma e^2 = (m_e/m_p)^1(m_e m_p)(G_p - G)(G_e - G)/(G_p - G)$$

and lastly two protons give

$$\gamma e^2 = (m_e/m_p)^2(m_p m_p)(G_p - G)(G_e - G)/(G_p - G)$$

all of which have the same factor in G, namely $(G_e - G)$.

We can see straight away that there is a consistency in these equations. Designate the term m_e/m_p by the label Q^{-1} since it is just the inverse proton/electron mass ratio Q, and all the equations reduce to

$$\gamma e^2 = (Q^{-1})^n(m_1 m_2)(G_e - G)$$

where n is a power corresponding to the number of protons in the system, and m_1, m_2 are the explicit masses of its members. And this is the transformation that ensures an observer sees the same electrical behaviour in these four systems at all times.

Theoretically this could be further generalised to include any pair of charged particles, provided Q is suitably adjusted to express the mass ratios of the particles concerned with respect to m_e , this quantity being of course the basis for the term G_e . The power factor would then pertain to the number of heavy particles involved. For example, the correct form for a muon bound to an antimuon (would you believe muonium? It has been transiently generated but decays at a speed close to our limits of resolution) would be

$$\gamma e^2 = (m_e/m_\mu)^2(m_\mu m_\mu)(G_e - G)$$

so a completely general form would be

$$\gamma e^2 = (Q_i^{-1})^n(m_1 m_2)(G_e - G)$$

where Q_i is general term representing the mass ratio of the heavier particle with respect to the electron and n is the number of heavy particles involved.

Finally if we really want to, we can reduce this further to

$$e = \pm 2\sqrt{\pi \epsilon_0 (Q_i^{-1})^n(m_1 m_2)(G_e - G)}$$

but we would still be better to keep it as

$$e/\sqrt{\epsilon_0} = \pm 2\sqrt{\pi (Q_i^{-1})^n(m_1 m_2)(G_e - G)}$$

because charge really cannot be considered in isolation from the permittivity of space.

No doubt by now the astute reader will have spotted that each of the above equations actually reduces to the now familiar

$$e = \pm 2\sqrt{\pi \epsilon_0 m_e^2 (G_e - G)}$$

so one could be excused for asking why was it necessary to go through this extensive analysis? The answer is frankly, to show that it could be done! Actually it is rather more than that. Until it was done we could not know that the expression for charge did not apply only to electrons. Now we know that it is general.

In past times when G was large enough to be significant, the above transformation would reduce the electrical component of the force by reducing the parameter e , but the total force between two particles would not change from the viewpoint of a normal observer. Thus atoms would not change their characteristics with time. Furthermore as it is the total force between particles that determines their dynamics, the distinction between the electrical and gravitational components does not have to be made except where it is explicitly necessary.

We can thus say with some confidence that electric charge is just the assigned source or parameter required to provide a corrective force when we transform gravity from the reference frame of one particle in the field of another to the reference frame of the everyday observer. This is all very nice, but even yet our troubles are not over. Gravity always attracts, whereas electric force is bipolar. Like charges repel and unlike charges attract. How do we fit this into our scheme?

The above equation tells us that there must be two types of charge from a mathematical point of view, but it tells us nothing about the physics of the situation, that is, just why it should be so. Not surprisingly, reversal of vector time is involved⁵. In effect two electrons repel because we see them both in forward time wherein electricity has to work against gravity. Whereas we see one of the pair in an unlike couple operating in reversed vector time - time as it applies to quantum states. This version of time is quite reversible, and it inverts the force that we see. If we were to see both particles in reverse time, again they would be seen to repel. This of course is just what we see two positrons do.

The bipolarity of charge only affects the transformation by requiring us to recognise the vector sense of the electrostatic field as derived from charge on the left-hand side when we take the root of e^2 . Now this is fine mathematically, but we need to delve into the physics of the situation to actually see what is going on. Again it was Dirac who gave us the model that solves our dilemma. Recall that he postulated a negative energy universe and went on to populate it with negative mass particles of all kinds.

Today we can dispense with the negative universe as such and say simply that the physics of the situation, given Heisenberg's uncertainty principle allows the vacuum to be teeming with virtual pairs of particles. This is the quantum fluctuation of the vacuum. These pairs are not exactly mass-negative, (though they can be so treated if desired) but are so short lived that they don't get the chance to manifest as real objects. Their energy however is real and can be demonstrated (the Casimir effect). If we inject energy into this milieu, we can literally knock virtual pairs into reality. But let's for the moment stay with Dirac. His model, if a little simplistic, is apt for our purpose here.

According to him, when an electron is elevated into real space by the injection of $2m_e$ units of positive mass-energy into this negative energy space it leaves a hole representing an absence of negative mass in its own space. This hole is a negative of a negative so must thus be seen in real space as having positive mass, and it must have a positive time sense because we cannot actually operate in reverse time. But the hole, now a real particle, spins in reverse.

The inference is that time has a reverse vector sense in negative space, so when elevated to real space, the hole is seen by us to be spinning in reverse. This is how we deal with time inversion. We have to reverse the length dimension, so things go backwards. The object we get by materialising an electron of course is its twin, the positron, and the reverse spin is just its way of showing us that it is actually a reverse-time object. The other effect of this is to reverse the polarity of its charge as well so that electrical forces associated with it will act the other way.

This completes the appraisal of the gravitational electron, given G as a variable.

References and notes;

1. According to general relativity, time dilation at an event horizon, is infinite. In special relativity, time dilation obeys the Lorentz transformation, such that

$$t = t_0 / \sqrt{(1 - v^2/c^2)}$$

where v is the velocity of the object under observation. However, in general relativity this becomes the velocity in radial free fall of a body in the gravitational field of another mass. In other words the velocity of arrival, which is the same as the velocity of escape, (but in the opposite vector sense of course). Since the escape velocity at an event horizon is c , time dilates to infinity - that is, a clock on that surface simply does not run at all.

2. Einstein showed that when one observes a moving charge, because the field transmits at c , by the time another charge is able to respond to the moving charge, that one has moved to a new position so the second charge is seeing the first at some time in the past.

To an inertial observer, this represents an anomaly requiring a small force vector to act as a correction, and this is magnetic force. The transformation that has to be made is the Lorentz transformation, and this produces a mathematical definition of the new force.

In general if we perform a corrective transformation on a force field, the transformation factor will itself be dimensionless. It is like a scaling factor, and from the dimensions of the system the correction will itself be a force.

In the case of the frames of reference of the electron and a modern observer, there is no consideration of velocity involved in the simple case. The transformation is simply a scaling of the modern observed force to the ancient

force by the ratio of the strengths of gravity then and now.

Einstein's groundbreaking paper is

A. Einstein, "On the Electrodynamics of Moving Bodies" translated and collected with other major papers on special relativity in; "Special Theory of Relativity" by C.W.Kilminster, Pergamon Press, 1970

The original paper was

A. Einstein; "Zur Electrodynamik bewegter Körper", Annalen der Physik, 17, 891 (1905).

3. A not-too-heavy exposition on gravitational radiation ;

Davies, P. C. W.; "The search for gravity waves", Cambridge University Press, 1980

4. There is an assumption here that may or may not be valid, and that is that the rate of decline in G is coupled to the rate of the expansion of visible spacetime. A naïve approach might suggest that it is inversely proportional to the volume of space and so declines as the inverse cube of the radius of the observable universe. That is

$$G = k/H^3$$

Where H is the Hubble limit. This would allow that for every doubling of the size of observable space, G would decline to one eighth of its former value, every trebling to one twenty seventh and so on. Such a decline would be quite catastrophic initially, reducing G to close to its modern value in perhaps as little as a century after the big bang.

5. A good account of time reversal symmetry is given by

Sachs, Robert Green, "The physics of time reversal", University of Chicago Press, 1987.

W.M.M. January, 1999