SEARCH FOR EFFECTS OF ELECTRIC POTENTIALS ON CHARGED PARTICLE CLOCKS

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ABSTRACT

Results of experiment to confirm a theory that links classical electromagnetism with the geometry of space-time will be described. The theory, based on the introduction of a Torsion tensor into Einstein's equations and following the approach of E. Schrödinger, predicts effects on clocks attached to charged particles, subject to intense electric fields, analogous to the effects on clocks in a gravitational field. We show that in order to interpret this theory, one must re-interpret all clock changes – both gravitational and electromagnetic – as arising from changes in potential energy and not merely potential. The clock is provided naturally by proton spins in hydrogen atoms subject to Nuclear Magnetic Resonance trials. No frequency change of clocks was observed to a resolution of 6×10^{-9}. A new "Clock Principle" was postulated to explain the null result. There are two possible implications of the experiments: (a) The Clock Principle is invalid and, in fact, no metric theory incorporating electromagnetism is possible; (b) The Clock Principle is valid and it follows that negative rest mass cannot exist.

INTRODUCTION

The goal of the present work is to investigate an electromagnetic alternative to exotic physics for the purpose of coupling matter to space-time. Electromagnetic forces have distinct advantages. They are 10^{40} times stronger than gravity. They can be manipulated at will. Resources to create intense fields of virtually any geometry are readily available. However, there is currently no accepted theory linking electrodynamics directly with the geometry of space-time other than to curve it via extremely high energy densities. The mainstream approach taken is "bottom up", attempting to unite all forces in the context of quantum gauge field theory which has to-date been successful in unifying the weak and electromagnetic forces and describing the strong force in what is known as "the standard model". Gravity and therefore space-time geometry remains isolated from the internal geometry of gauge theory. If such a theory could be found and even its simplest predictions tested and verified, then there would be hope that electromagnetic coupling to space and time might be possible. This could lead to new interpretations and possibly new effects in gravitation and electromagnetism.

The experiments described in this work measure the predictions of a theory[1], linking space-time geometry and electrodynamics. This is grounded upon E. Schrödinger's later works on gravitation theory[2]. In his work, Schrödinger attempted to link electromagnetism to geometry through a non-symmetric affine connection (Torsion tensor). He failed at the attempt, primarily because of an error of oversight. The theory upon which the present work is based corrects this error[3], resulting in the definition of a new type of affine connection – an electrodynamic connection – that precisely matches Schrödinger's concepts.

THEORY

We describe a simplified theory and shall only write the new field equations and their solutions for the present case. The theory is summarized in the BPP final report*. The governing equations are:

$$G_{\mu\nu} = -\frac{\kappa}{2} u^{\sigma} (F_{\nu\sigma;\mu} + F_{\mu\sigma;\nu}) \tag{1}$$

$$F^{\mu\tau}_{\ ;\tau} = 0 \ ; \quad F_{\mu\nu;\sigma} + F_{\nu\sigma;\mu} + F_{\sigma\mu;\nu} = 0 \tag{2}$$

$G_{\mu\nu}$ is the Einstein tensor. $F_{\mu\nu}$ is the Maxwell electromagnetic field tensor. u^{λ} is the test particle 4-velocity and κ = -e/mc2, the charge/mass ratio of the test particle. Greek indices range from 0, the time index, to 1,2,3, the space indices. Equation (1) is the modified Einstein equation including Electrodynamic Torsion. Equations (2) are the usual covariant Maxwell equations. Selecting a metric for an appropriate

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geometry results in a set of solvable differential equations coupling the metric and electromagnetic field variables.

Ideal Experiment

The theory predicts that a particle of charge e, and mass m, immersed in a suitable electric field but unshielded and supported will see, in its rest frame, a time differing from the proper time of an external observer arising from the electrostatic potential at its location. In general, from the theory, the time shift in a clock interval is related to the potential difference between two points:

$$\frac{d\tau_2}{d\tau_1} = 1 + 2\kappa(\varphi_2 - \varphi_1) \qquad (3)$$

This equation is exactly analogous to that for the gravitational red shift.

One possible clock for such a test is Nuclear Magnetic Resonance. A proton placed in an intense electric field within a radio-frequency transverse field "H_1" coil aligned orthogonally to a uniform magnetic field, H_0, is resonant at the Larmor frequency, $\omega = \gamma H_0$, where the gyromagnetic ratio, γ, for the proton spin is proportional to e/m. We thus have a natural clock. From eq. (3) we expect the proton's clock frequency to depend on its relative positions r_1 and r_2:

$$\omega(r_2) = \omega(r_1)\left[1 + 2\kappa(\varphi_2 - \varphi_1)\right] \qquad (4)$$

The Larmor field distribution is then given by

$$H(r_2) = H(r_1)\left[1 + 2\kappa(\varphi_2 - \varphi_1)\right] \qquad (5)$$

From this it is straightforward to calculate the NMR lineshape and shift that will result when the electric field is turned on as compared to the field off. Under ideal circumstances, for a supported proton in a 8T magnetic field with a 5kV/cm electric field, a line shift and broadening of approximately five parts per million is expected. The expected NMR lines are modeled in the "Experiments" section.

Present Approach

In practice it is experimentally difficult to "support" a charged particle. Generally, this can be accomplished electromagnetically, but then, by definition, the electric field and force at the particle location must vanish since the charge does not accelerate. The approach we have chosen uses the proton in a hydrogen atom. It is supported electromagnetically. The consequences of this approach will be the main subject of the conclusions of this work. A detailed description of the three experiments performed follows.

EXPERIMENTS

Three experiments were performed: A temporally and spatially constant potential applied to the proton in the hydrogen atom; A time-varying but spatially constant potential applied to the proton in the hydrogen atom; A hydrogen atom physically displaced through an intense electric field.

Experiment 1 – Constant potential

A 354 MHz, 8.4 Tesla NMR system was chosen for the experiments. This magnet has a field homogeneity of 0.1 ppm or about 35 Hz, more than sufficient to resolve small effects. The proton sample was Benzene. The initial experiment was a simple free induction decay (FID) with the E-field on vs. off. The sample was enclosed in a 2mm thick aluminum can (Fig. 1) placed at high potential. Thus the E-field will vanish in the interior of the can at the sample but there will remain a constant potential. The voltage terminal (sample chamber) could be set + or – with respect to ground and the NMR FID was monitored.

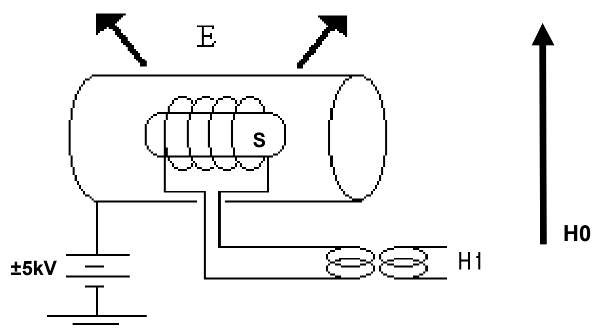

Figure 1. NMR "can" arrangement. External magnetic field, H0, is perpendicular to the radio frequency field, H1, applied through a coil wrapped around the proton sample, S. The 5kV electric field is applied outside the can leaving a constant 5kV potential inside.

A field homogeneity of 10 ppb was achieved for the 8.4T field, sufficient to resolve the smallest predicted effects. The observed line shift, was $\Delta\nu/\nu \le 0 \pm 1.0\text{x}10^{-9}$, consistent with a null prediction of both classical E&M and the present theory. The null result is consistent with both classical theory and the present one.

Experiment 2 - Time-varying potential

The second experiment, a time-varying potential applied to the proton in the hydrogen atom, was initially expected to produce an effect. However, it was found during the course of this program that this theory was also invariant under a pure time-varying potential[5], a result consistent with the classical "Lorentz gauge condition" which is the relativistic generalization of the Coulomb gauge condition. That is, it states that the potential is also arbitrary to an additive time-derivative of a scalar. Thus, a null result was also expected and was observed. A "spin-echo" experiment was performed to observe any phase shift introduced by the time varying electric field. Extreme care was taken to calibrate the system to ensure that any small phase shift could be identified and that stray currents would not affect the data. Upon application of a 5KV step-function (20 ms risetime) between the aluminum can and ground in both turn-on and turn-off modes, the observed shift in the NMR line was $\Delta\nu/\nu \le 0 \pm 1.0\text{x}10^{-11}$.

Experiment 3 - Physical displacement of Hydrogen atom through high electric field

For the third and final experiment, hydrogen in benzene at room temperature was gravity-flowed between two electrodes, an upper one at ground potential and a lower one at +5000 V, both situated in the NMR coil in the external 8.4T magnetic field while NMR was performed with the electric field on and off. The electrodes were copper discs placed in the 3mm I.D. of glass tubing and connected to a high voltage source through glass/epoxy seals. The electrode spacing was 1.0 cm giving an average electric field of 5000V/cm. The 2-turn NMR coil diameter was 1.5 cm ensuring that the HV region was inside the coil. The coil was untuned to avoid radiation damping since the signal was already very large. Figure 2 shows the NMR coil system arrangement and a photo of the open chamber.

An NMR FID experiment was performed with and without flow. A 20-30 ms T_2 was obtained by careful adjustment of the B-field shim coils. The NMR line and effects of flow without the presence of an E-field were modeled. The T_2 value gives a line width of approximately 17 Hz ($\Delta f = 1/\pi T_2$). Figure 3 shows the measured NMR line with voltage off as a function of flow velocity through the coil varying from 3 cm/s to 50 cm/s. Since the FID has a time constant of 20-30 ms, the proton must stay in the H1 field at least this long in order to contribute a significant time-shift signal arising from the maximum 5kV potential change. This corresponds to a flow speed of 15-30 cm/s, the mid-range of the chosen flows. Note that the measured shift with zero volts is approximately 10 Hz, from 0 to 50 cm/s flow rate, in approximate agreement with the theoretical calculation, Figure 3. Figure 4 shows the predicted lines for a maximum potential of 5000 Volts. The shift is at least ten times that for zero volts.

For the flow experiment, the NMR line was obtained for voltage off, voltage on, and a dummy voltage on (voltage on but HV cable disconnected). The probe voltage was discharged when the dummy experiment was performed. Figure 5 shows data for flows of 0, 3, 6, 12, 25 and 50 cm/s with the voltage applied .

We note in Figure 5 that there is no change in the line positions greater than the FFT resolution of $\pm$ 2 Hz corresponding approximately to a line shift of $\Delta\nu/\nu \le 0 \pm 6.0\text{x}10^{-9}$, at least a hundred times smaller than the predicted shift of Figure 4. Figure 3 is therefore representative of the results with applied field as well.

When the experiment was completed, the probe was disassembled and carefully inspected to ensure that all voltage connections were secure.

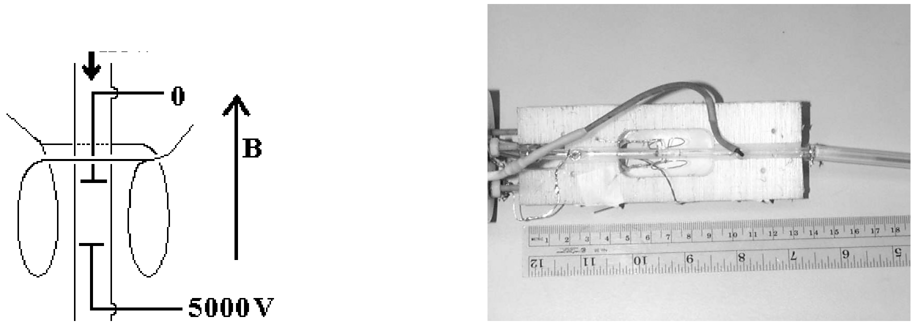

Figure 2.   Diagram and photo of NMR coil and flow arrangement for E-field experiment

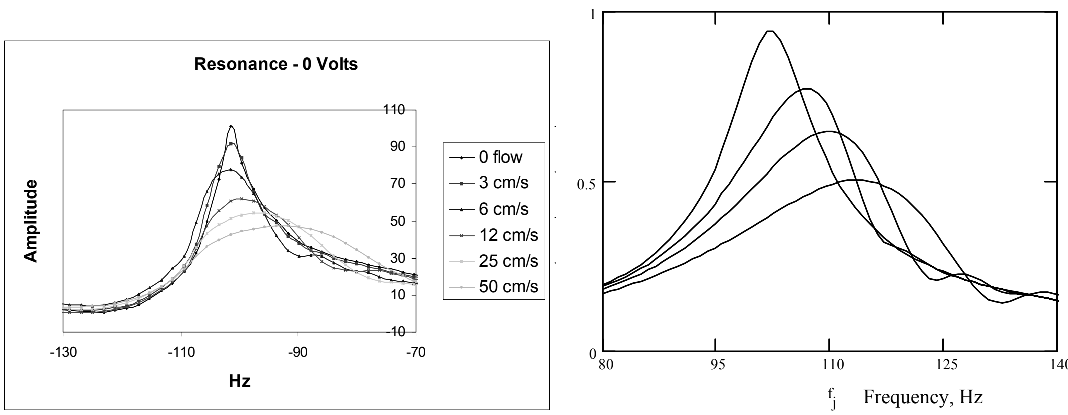

Figure 3.   Measured NMR lines (left) and calculated (0,12,25,50 cm/s) for zero E-field and flows from 0 - 50 cm/s.

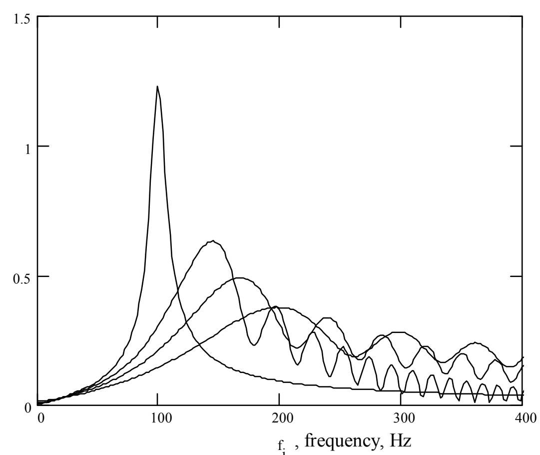

Figure 4. Calculated NMR lines for 5000V/cm E-field for flows of 0, 12, 25 and 50 cm/s.

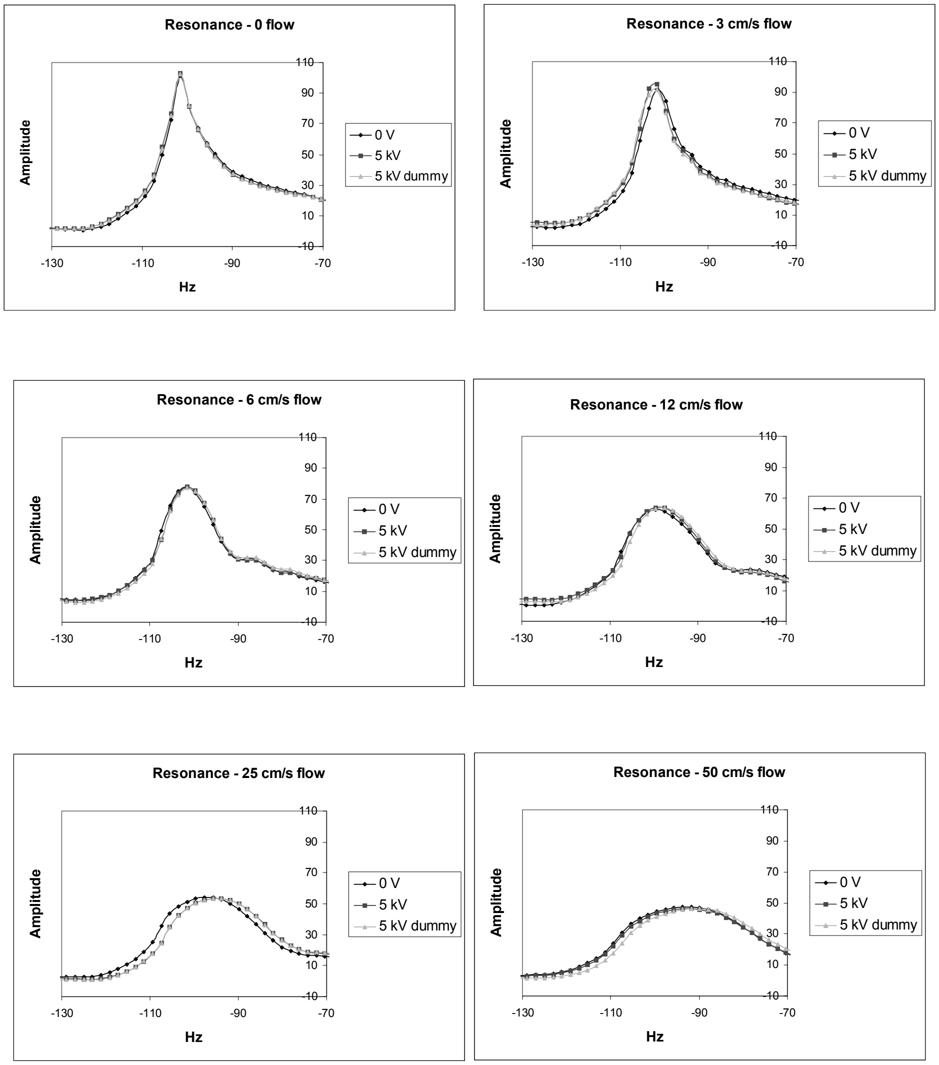

Figure 5. Measured variation in NMR line at 0, 6, 25 and 50 cm/s flow with applied voltage.

CONCLUSIONS

Experimental Conclusions

All three experiments showed null results. The first experiment, constant potential applied to the proton in the hydrogen atom, produced a null result as expected and explained earlier. The second experiment, a time-varying potential applied to the proton in the hydrogen atom, also produced a null result as expected and explained. From the second experiment we have learned that the present theory is relativistically Gauge Invariant in the context of Maxwell's equations – as it should be.

The third experiment, physical displacement of a proton in a hydrogen atom through an electric field, was expected to produce a frequency shift of 5ppm in the NMR line. No change was observed to high precision. This could be explained as follows. When a hydrogen atom is placed in an electric field, classically, only one effect is produced – an induced dipole moment of the atom resulting from the stretching of the electron orbital. Otherwise, no work is done on the hydrogen atom (except for the exceedingly small amount involved in stretching) since the work done on the proton is cancelled by the opposite work done on the electron(due to its negative charge) in the electric field. Furthermore, it is straightforward to show[4] that no work is actually done on the proton itself since the electric force on it is precisely balanced by an opposing force, in the field direction, from the electron.

Implied Conclusions

If we substitute potential energy change and therefore work done rather than simple potential in the metric, then the fact that no work is done on the proton because of the electron's influence can explain the null result. We now discuss the relation of work to the metric.

Relation of the Metric to the Lagrangian and Work Done

Let $\tilde{L}$ be defined as the specific Lagrangian or Lagrangian per unit rest energy,

$$\tilde{L} = \frac{(T - V)}{mc^2} \tag{6}$$

where T, V and m are the kinetic energy, potential energy and rest mass of the test particle respectively.

Suppose we are at rest at some height z in a gravitational field, so that $T=0$ and $V=mgz$, then $\tilde{L} = gz/c^2$. We have shown for weak fields and nonrelativistic speeds that the proper time element can be written in terms of the Specific Lagrangian and coordinate time element as:

$$d\tau = \sqrt{1-2\tilde{L}}\ dt \tag{7}$$

This describes the behavior of clocks. Consider two positions in the gravitational field z_1 and $z_2 = z_1 + h$. Assume a proper time interval $d\tau_1$ at z_1 and $d\tau_2$ at z_2. Then, for weak fields:

$$\frac{d\tau_2}{d\tau_1} = 1 - \frac{gh}{c^2} \tag{8}$$

We can rewrite this in terms of potential energy and Lagrangian rather than potential;

$$\frac{d\tau_2}{d\tau_1} = 1 - \frac{mgh}{mc^2} = 1 - (\tilde{L}_2 - \tilde{L}_1) = 1 - \Delta\tilde{L} \tag{9}$$

In general, a variation in the Specific Lagrangian results in a change in the clock rate. Referring more concisely to the metric for a single particle, p, we may express the Lagrangian change more clearly in terms of the net conservative work, W_c, done on p.

$$\Delta\tilde{L}_p = 1 - \frac{(\Delta T - \Delta V)}{m_p c^2} = \frac{\Delta T_p + W_c}{m_p c^2} \tag{10}$$

The weak-field, non-relativistic, metric for a given particle, p, acted upon by forces and hence net conservative work, W_{cp}, done upon it by all other particles in the field is given by

$$d\tau_p{}^2 = \left(1 - \frac{2W_{cp}}{mc^2}\right)c^2 dt_p{}^2 - dx_p{}^2 - dy_p{}^2 - dz_p{}^2, \tag{11}$$

We have rewritten the metric in this way because potential is not well-defined except through potential energy and work, where it is defined as work per unit mass in gravitation and work per unit charge in electromagnetism.

The Clock Principle

In the previous section we found a simple Lagrangian formulation that places gravitation on an equal footing with our theory in regards to changes in the temporal portion of the metric. The Lagrangian formulation deals with kinetic and potential energy changes. Clocks raised in a gravitational field are at rest in the two positions and can be slowly moved between them. Thus the Lagrangian becomes simply the negative change of potential energy(work done on) of the clock, moved from the lower position to the upper. However, we must be careful and can no longer use the word "clock" loosely. When we refer to "clock" henceforth, we mean the *mechanism of the clock*. Thus we mean that work is performed on the *mechanism*. Clearly all clock mechanisms are driven by energy changes. What is not as obvious is that the mechanism of any clock must reflect the proper time variations in a gravitational field. For example, the mass-spring mechanism of a simple clock must somehow change with different heights in a gravitational field. Similarly, a pendulum clock must exhibit changes in its mechanism. Even an atomic clock is subject to this consideration. This brings us to the ***first clock postulate***:

1) Every clock has a mechanism which must be held accountable for observed changes in its measurement of time.

We shall now examine the relationship between work and changes in clock time in a gravitational field. We use the notation "nc" to mean nonconservative and "c" for conservative forces.

Einstein Rocket -- Equivalence Principle for clock changes in a Gravitational Field

We shall employ the famous Einstein rocket "gedanken-experiment" to demonstrate our concepts. Consider a rocket lifting a mass, m, by a stiff wire in a gravitational field. Let us suppose that we adjust its thrust to precisely oppose the graviational pull on the mass. The rocket-mass system is now balanced and hovers, for example, at the surface of the earth. An arbitrarily small external force, $\vec{\varepsilon}$, may now raise the system to a height, h. This is shown in Figure 7. The force $\vec{\varepsilon}$ does no work on the system since it can be made arbitrarily small. However, upon rising a height h, due to the infinitesimal assistance of the guiding force, the rocket does work on the mass m. The potential energy of the mass is V_1 at the surface and V_2 at height h.

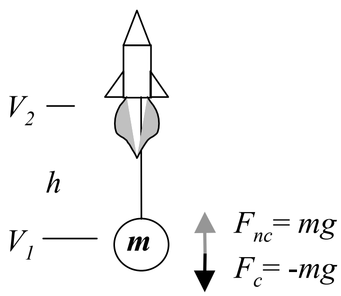

Figure 7. Balanced force configuration of a rocket-mass system

In this situation, the nonconservative force is that of the rocket. This is equal and opposite to gravity. We make the following definitions:

$$z_2 - z_1 = h \;;\; d\vec{s} = dz\hat{k} \;;\; \vec{g} = -g\hat{k} \tag{12}$$

Then the non-conservative work performed on the mass m by the rocket is

$$W_{nc} = \int_{z_1}^{z_2} \vec{F}_{nc} \cdot d\vec{s} = mgh \, . \tag{13}$$

and the conservative work done on m by gravity, opposing the rocket is:

$$W_c = -mgh = -(V_2 - V_1) = -\Delta V \tag{14}$$

<u>Einstein rocket replaced by negative mass</u>

Let us now reconsider the rocket of Figure 7. We can replace the rocket by negative mass equal in magnitude to the lower positive mass (Fig. 8). Earth's gravity repels negative mass and thus an amount *(-m)* will precisely balance the force of attraction on m, a situation equivalent to the rocket.

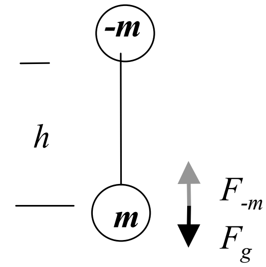

Figure 8. Balanced force configuration for rocket replaced by negative mass

We evaluate the work done in this situation. There are two forces acting on m, $\vec{F}_g$ and $\vec{F}_{-m}$. This time *both* forces are conservative. The total work done on the mass m is zero because there is no change in the kinetic energy, since $\vec{F}_{-m} = -\vec{F}_g$.

$$W_{total} = \int \vec{F}_g \cdot d\vec{s} + \int \vec{F}_{-m} \cdot d\vec{s} = \Delta T = 0 \tag{15}$$

However, now the total work done on m is conservative since, unlike with the rocket, there are no non-conservative forces acting. The rigid wire transmits the conservative force from $-m$. Thus we find:

$$W_c = W_g + W_{-m} = 0 \tag{16}$$

This model of a massive neutral dipole is exactly equivalent to an electric neutral dipole such as the proton and electron of a hydrogen atom in an electric field. In the latter case, the two forces acting on the proton, the external electric field and the opposing force of the electron are both conservative. The total conservative work on the proton is zero when the atom is moved a distance h through a known potential difference. That is precisely our experiment. There was no clock change observed.

This leads us to the ***second and third Clock Postulates***:

2) External conservative work done on a clock mechanism is responsible for changes in its rate when the motion of the clock can be neglected.

3) When the clock is not at rest, the change in its rate arises more generally from the change in the Specific Lagrangian for the mechanism.

The third postulate takes into account the change when there is kinetic energy present.

These postulates reconcile the observations and considerations of the present experiment with those observed for gravity. Therefore one should not expect to see a clock change in the imagined massive dipole experiment since there was no net conservative work done on m.

Inconsistency between General Relativity and existence of a neutral mass dipole

Now consider a clock on the mass *m* attached to the rocket. The mass *m* might itself be part of a clock mechanism. Upon reaching height *h*, the clock will change. But the mass *m* cannot distinguish between the pull of the rocket on the wire from that of the negative mass. In the case of the negative mass , the Clock Principle states that since no net conservative work is done on *m* , no clock change should be observed. So, there is a conflict here. It follows that:

Since we assume GR to be true, either the Clock Principle is false or a mass dipole cannot exist as the analogue of a charge dipole. Thus, if the clock principle is true, negative mass cannot exist. If the clock principle is false, then work and energy change are not related in general to time change. It follows that a metric theory of forces other than gravitation cannot be constructed.

Clock Conclusions

It is generally agreed that in order for a clock to indicate the passage of time, energy change in the mechanism is required. Thus, it appears that space is coupled to time through energy. When a clock is raised in a gravitational field, external work is performed on the mechanism. This permits a time change. If W_c =0 so that applied forces opposing conservative forces are also conservative, then there will be no observed clock change.

We have shown that if the clock principle is correct then ***negative mass cannot exist***. This does not preclude the existence of negative energy since the general energy-momentum relation has two roots,

$$E = \pm\sqrt{p^2c^2 + m^2c^4}$$

of which the positive root, in the rest frame of a particle of mass m (p=0), is the famous Einstein energy-mass relation.

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