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Measuring the speed of gravity and/or the Coulomb force

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Abstract

The Newtonian theory of gravity implies that there is an instantaneous response of a test mass to a gravitating body even if it is light years away. General and special relativity, on the other hand, require that nothing (with the exception of particles with imaginary rest mass or wave packet phase velocities) may travel faster than light. If gravity travels at the speed of light, however, there may be a problem with 'aberration' and non-normal gravitational components in the gravity of a source mass acting on the orbit of a test mass[5]. Recent estimates[1,2] from gravitational tides on the Earth seem to confirm that gravity propagates at light speed. Nevertheless, another recent estimate[9] considering lunar-solar gravitational effects on satellite motions came to the conclusion that gravity travels faster than light. This then implies that the need for a 'retarded' correction to the Newtonian force is in doubt. The experiment proposed may be performed with modern sensors to allow measurement of the speed of gravity to be made in the laboratory. If there is no aberration, then no time delay should be measured in the proposed experiments. The experiment may also measure the speed of the Coulomb force to confirm the absence of aberration there as well. Experimental evidence for the absence of aberration in the Coulomb force seems to already exist[8] supporting the need to independently confirm these findings.

Keywords

Gravity; Speed; Force.

INTRODUCTION

The idea in this paper is to describe an experiment to measure the propagation speed of gravitational forces in a laboratory equipped with state-of-the-art sensor equipment. Up to now, two attempts were made to measure this using astrophysical interactions such as occultation of a quasar by Jupiter[1] and tidal effects of the Sun and Moon on Earth[2]. Both of these have offered preliminary evidence that gravity propagates at the speed of light, c. On the other hand, a study based on data for lunar-solar corrections to the motion of geo-synchronous satellites indicated that their motion was consistent with instantaneous gravitational force transmission from the sun[9]. None of these experiments, however, should be taken as the final word on the matter until a series of direct laboratory measurements of the speed has been established. This paper proposes that such an experiment may now be performed using state-of-the-art measurements with relatively high-tech sensor systems. The measurement resolutions required are timing discrete events to nanosecond (ns) accuracy and measuring forces to micro-N (mu-N) accuracy. One previous paper[3] has referred to a system similar to that which will be described, but the proposed system appears to offer some advantages. It is expected that relativity will once more be verified and a speed of gravity equal to c found. Ideally, several teams would perform independent tests of this sort, allowing replication and verification to ensure that the results are indeed conclusive.

One of the first researchers to discuss a possible trans-luminal speed of gravity was Van Flandern and, more recently, Rowlands[5]. They pointed out the distinction between the speed of gravitational waves, presumed to be c, and the speed with which bodies attract one another when not necessarily moving rapidly enough to produce gravitational waves. Newton also considered gravitational attraction to be essentially instantaneous. Van Flandern points out that for a stationary source and a moving target as shown in Figure 1, the target sees the source to be in a position displaced from the apparent source of gravity. It is assumed here that the source's movement in the inertial frame of an observer hovering 'over' the scene is negligible.

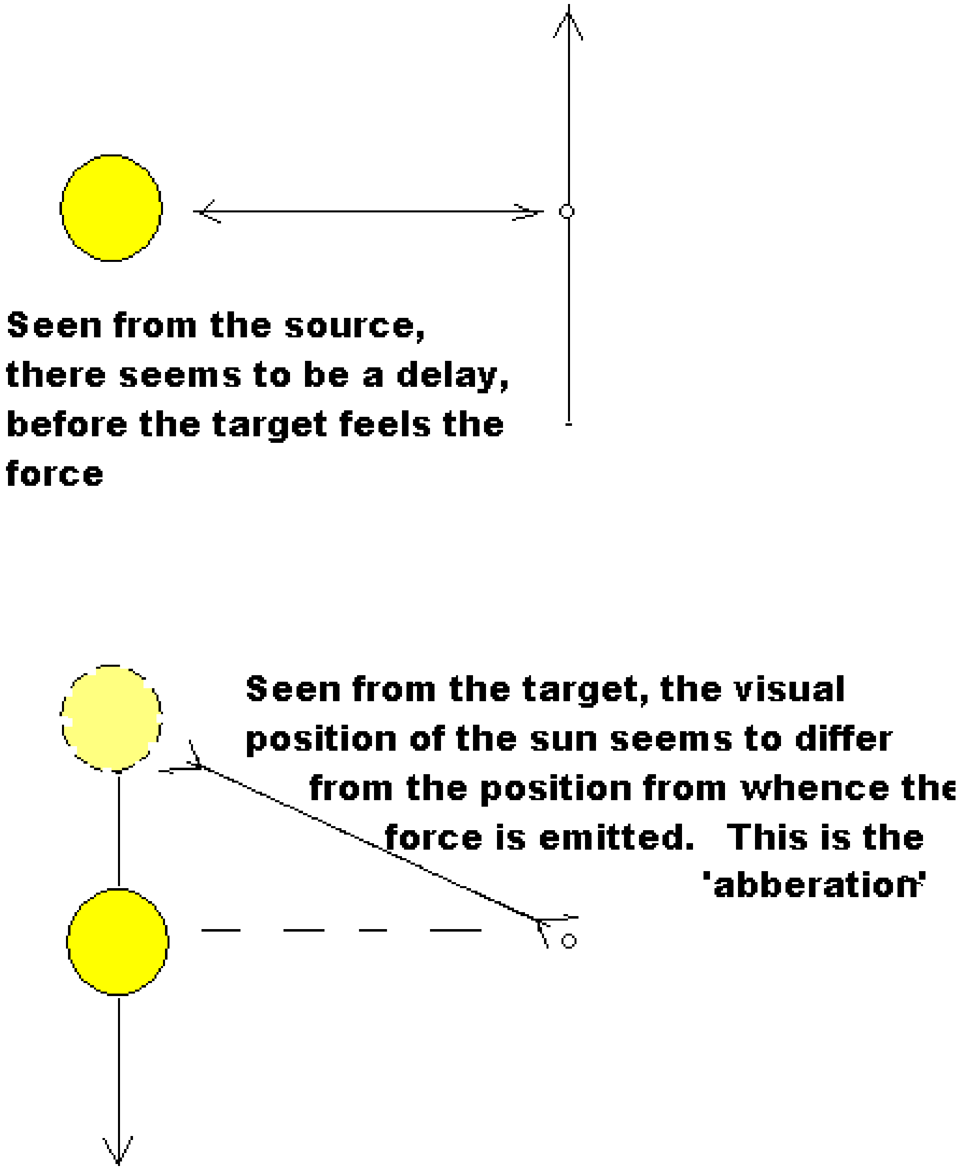
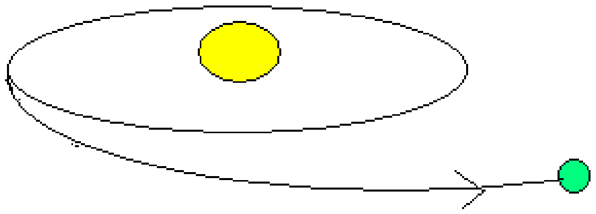


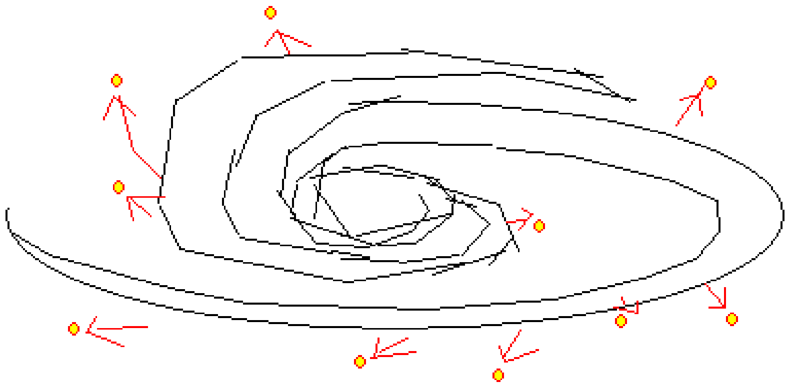
Figure 1 : A small test mass or 'target' moves past a large 'source', where the movement of the source in inertial space is taken to be negligible.

It is plain from the lower half of Figure 1 that if gravity really did travel at c, then the force would be along the diagonal line, leading to a component along the direction of motion of the body. That is, it would tend to accelerate the body in the direction of motion as well as in the direction normal to it. But for a circular orbit, the force should always be normal to the orbiting body. In the case of the Earth, with a light travel time of about 8 minutes from Sun to Earth, the Sun would appear to gravitate from a point 8 minutes 'behind' the apparent position of the Sun. This along-track force, though small, is sufficiently large to cause the Earth to double the semi-major axis of its orbit roughly once every 1,200 years. Thus all planets would spiral outward and be lost in space. Obviously this does not happen. So either gravity acts instantaneously as Newton thought or acts at c and includes some 'retarding factor' to correct for the aberration. In general relativity, by insisting on conservation of momentum and energy, such a retarding effect is introduced.

The effect of an uncompensated aberration force on a galaxy would be even more disastrous. The stars would fly apart into the intergalactic void as illustrated in Figure 2. It would be the opposite of dark matter's binding effect. Note also that, while the time taken for light to reach the Earth from the Sun is 8 minutes, for stars on the edge of the galaxy, the light travel time w.r.t. to the centre is of the order of 50,000 years. Hence, gravitational attraction limited to light speed would pose an even bigger problem in this case, as the galaxy would have drifted through intergalactic space as well as there being an on-orbit shift of 50,000 years. Also, the Solar System orbits the galaxy in about 230 million years, so 50,000 years is 0.022% of the galactic 'year', while 8 minutes is only 0.00015% of a solar year.



Solar system instability due to aberration



Galactic instability due to aberration

Figure 2 : An 'aberration' force would cause instability in the Solar System as well as in galactic structure.

The presumed consequences of non-instantaneous gravity make it all the more imperative that the experiment considered herein should be carried out. By the same token, it is surprising that the experiment has not be done yet, since already Newton expressed major reservations against the 'action at a distance' implied by his equations.

The above arguments hold for all inverse-square central forces. Thus for the Coulomb force, one may ask if the propagation speed is the same as the wave speed of electromagnetic radiation. Indeed, a team of physicists at Frascati, Italy seems to have already found some evidence for 'rigid fields' carried by an electron beam[8]. Such fields presumably have no time lag and so essentially propagate instantaneously.

DESCRIPTION OF PROPOSED EXPERIMENT

Let us first examine whether these tests are viable by using the Newtonian approximation to gravitational acceleration. The test apparatus involves tungsten balls rotating at a modest angular velocity of 6,000 rpm with a moment arm of 39.67 cm, giving a tangential linear velocity of 249.26 m/s, i.e., 0.832 $\times 10^{-6}$ c. With these conditions, the Einstein Factor, gamma, is nearly unity:

$$\text{Gamma} = 1/(1. - 0.832 \times 10^{-6})^{1/2} = 1.0000004 \quad (1)$$

But since the force measurements need only be accurate to a few percent, this correction factor may be neglected, and we can simply use the Newtonian approximation for the force:

$$F = G\, m_1\, m_2 / r^2 \quad (2)$$

G is the gravitational constant, m_1 and m_2 are the test masses and r is their linear separated distance. The test set-up is indicated in Figure 3 below. Two balls rotate around a third, stationary one, which is placed off-centre in the enclosed path of the rotating balls. The rotating balls are mounted such that at one point in the revolution, both outer balls are equidistant from the central one thus cancelling the gravitational effects of the three-ball system. Balls of tungsten are used as a compromise between density and cost. To get a reasonable force, balls of less than 100 kg are considered. The radius of a sphere if 100 kg is about 10.7345 cm, where tungsten has a density of about 19.25 g cm^{-3}. The force between 2 balls of radius r, at a distance of 2.1r between their centres is $1.22\times 10^{-6} \times r$ N. So for a radius of 0.107345 m and a separation of 0.225 m, the force is 1.31×10^{-7} N. This is well within the range of modern force sensors, which can sense down to 10^{-9} N (e.g. FemtoTools force sensing probes go down to nano-N). So, in general, the larger the ball the better the result, but the smaller the easier the construction. Practical limitations means it is sensible to restrict the size to not much more than r = 10cm and thus masses of about 100 kg. Consider balls of 10 kg. They would have radius 4.98 cm. The force at 2.1 r would then be 6.1×10^{-8} N. This is just close enough to the force sensitivity limit. Also, such a scale is practical for a bench-top experiment.

In Figure 3(a) a graph of the calculated X and Y force components (based simply on Eq. (1) assuming point masses) as experienced by the central sphere are plotted against angle, where 0 deg corresponds to the sphere on the left in in Figure 3(b), which shows the initial configuration. As can be seen from the force graph, the symmetrical position, labeled 'p', illustrated in Figure 3(c), is the one point in the cycle where both X and Y force components simultaneously vanish. It can also be seen that there are in total three points where the X component vanishes and four where the Y component vanishes. Though the point p is of greatest interest in determining the speed of gravity (hereafter to be called vG), the other null points as well as the overall shape of the measured force can also give some indication of vG. Note that the force levels will be in the sub-micro-N range, which is routinely measured by state-of-the-art sensors. For example, the 'nano-science instruments'[4] range goes from nano-N to milli-N.

The light travel time between the rotating masses and the central one at the point where all forces balance (P in Figure 3(a) and illustrated in 3(c)), again assuming point masses, is 0.18m/c = 0.6 ns, hence the time measurement accuracy is on the order of 0.1 nano-seconds.

Figure 4 shows the force levels from Figure 3 plotted together with the light travel times between the two rotating balls and the central one, where Ball-1 is the lower one in Figure 3(b) and Ball-2 the upper one. Note that only for two of the points where forces cancel, one at 114.5 degand one around 290 deg, both rotating balls equidistant from the central one. If vG is instantaneous, the non-symmetric light-travel time for these cases should be as shown in the figure. Otherwise, if vG = c, then the measured force curve should lag the theoretical one (Figure 4) by the time difference. For point P and the other equidistant point there should still be a lag of about 1 ns w.r.t the simple Newtonian curve. This verifies the need for about 0.1 ns of accuracy in the measurements to put limits on vG.

We should also have a precise set of position measurements, perhaps with sub-ns accuracy, to compare with the timing of the force measurements. Note, that, if the system can rotate at 6,000 RPM, this implies that each milli-deg is traversed in 28 ns. So position accuracy should be one 300th of a milli-deg. With a rotor radius of 39.67 cm, this corresponds to tangential distance of 0.0019 microns or 1.9 nm! High precision laser reflection sensors may be suitable.

For such rapid rotation, a dynamically-balanced, rigid rotor is desirable. A notional system is illustrated in Figure 5 where the counterweight, at a moment arm 5 times that of the other masses, need only weigh 4 kg. It's gravitational force is negligible, as it is $(1/5)/(5^2)$ =0.008 times smaller than the others. If it is set on a pole 1 m above the plane of the other masses, its effect will be even less.

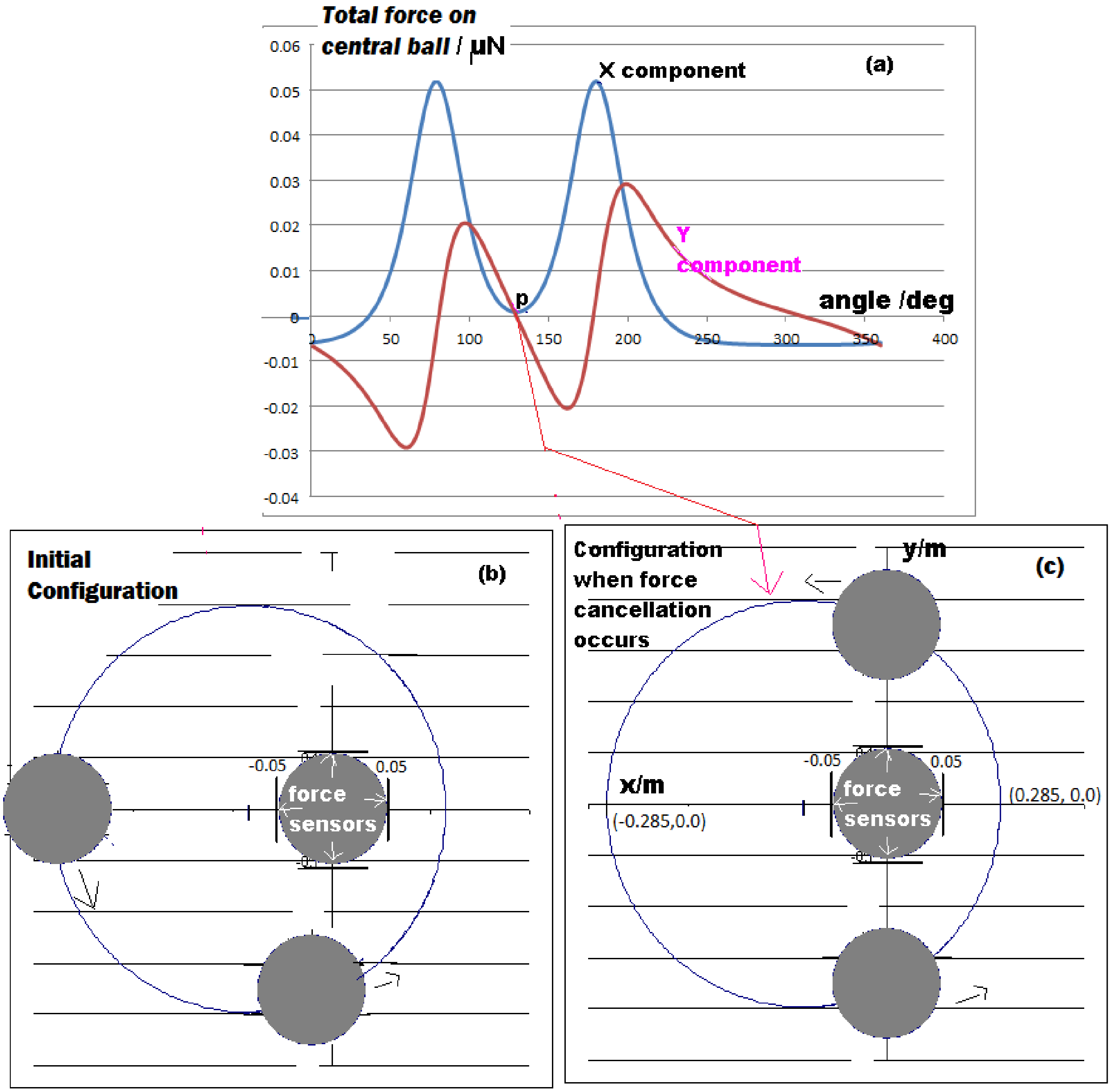


Figure 3 : Set-up of the experiment: Two tungsten balls revolving round a third one.

Now the positional accuracy requirement for nanosecond accuracy is 'only' about 0.10 microns if we use the longer arm as reference. In fact, if a large evacuated hall could be used, one could project a laser spot on a distant wall and further increase positional accuracy. Or a system of mirrors may be used to augment the accuracy.

It is important, as usual in ultra-sensitive experiments, to perform them in a vibration free environment. Though in this case a small residual vibration is not such a problem, as the periodic nature of the signal can be filtered out of the noise, especially if we have up to 10^9 samples per second. If the long arm proves incapable of providing sufficient stability due to wobble, one may simply eliminate the long arm and depend on having a very stable motor shaft for driving the rotation of the 2 balls.

Note that we might also consider a similar experiment for the Coulomb force. Even though electrons in an atom are not thought of as having classical orbits, this experiment may also address the speed of atomic-scale fundamental force propagation. Using a Van de Graaff generator producing about 1 MV, it may be possible to deposit 1 milli-coulomb on the three orbs and have two of them rotating about the third as depicted in Figure 6 below.

It would be necessary to use about 1 megavolt to maintain such a surface charge. Discharge to the atmosphere may be reduced by again having the system in vacuo. Note that here weight is not a problem, so we need no distant counter-weight. The force level in this case is much greater and given by:

$$F_c = 8.987 \times 10^9 q_1 q_2 / r^2 \qquad (3)$$

If q_1 and q_2 are +0.001 Coulombs and -0.001 Coulombs respectively, then there is an attractive force of 898.7/ r^2 N. The radius can become larger in this case, and even with r = 1m, the force is 898.7 N! Thus this version of the experiment would yield results of larger magnitudes and be easier to accomplish when considering the needed instrumentation. Indeed, we need not even have a rotating system, as with the much larger forces than for the gravitational case, one may use a static system, which is easier to deal with than one involving rapid rotation.

Van de Graaff generators take some time to charge up, and so are unsuited for static tests. Instead, two large capacitor plates spaced at 1m could be used, as shown in Figure 7. By pulsing the voltage in the circuit, it should be possible to measure the force on each plate using sensitive force sensors with nano-second resolution. Very short pulses of the order of pico-seconds are possible. The capacitance of such a capacitor would be C = A/d, where A is the area of the plates, which can be assumed to be 10^{-2} m^2 by using large square plates of 10cm x 10cm. The permittivity of air, e_0, is about 10^{-11} and d is plate separation, about 1 m. So C = 10^{-13} farad. It means that with precise, ultra-high power pulses of 10 MV, induced charges can be on the order of $Q = CV = 10^{-6}$ C. The force is fairly large; at 1 m it becomes $F = ½ CV^2/d$ = 5 N, and at 100 m it becomes 0.5 mN, which is easy to measure. The time taken for light to travel a distance of 100 m is 0.3 microseconds, which should also be easy to measure. If a large electret surface is used for one of the plates, then we only have to bias the other plate and measure when the electret side feels the force. While it is expected that the speed of c would be measured, anything measured faster would point to new physics. This experimental set-up could be constructed for relatively moderate costs, though again state of the art timing and sensors and high-voltage equipment need to be used.

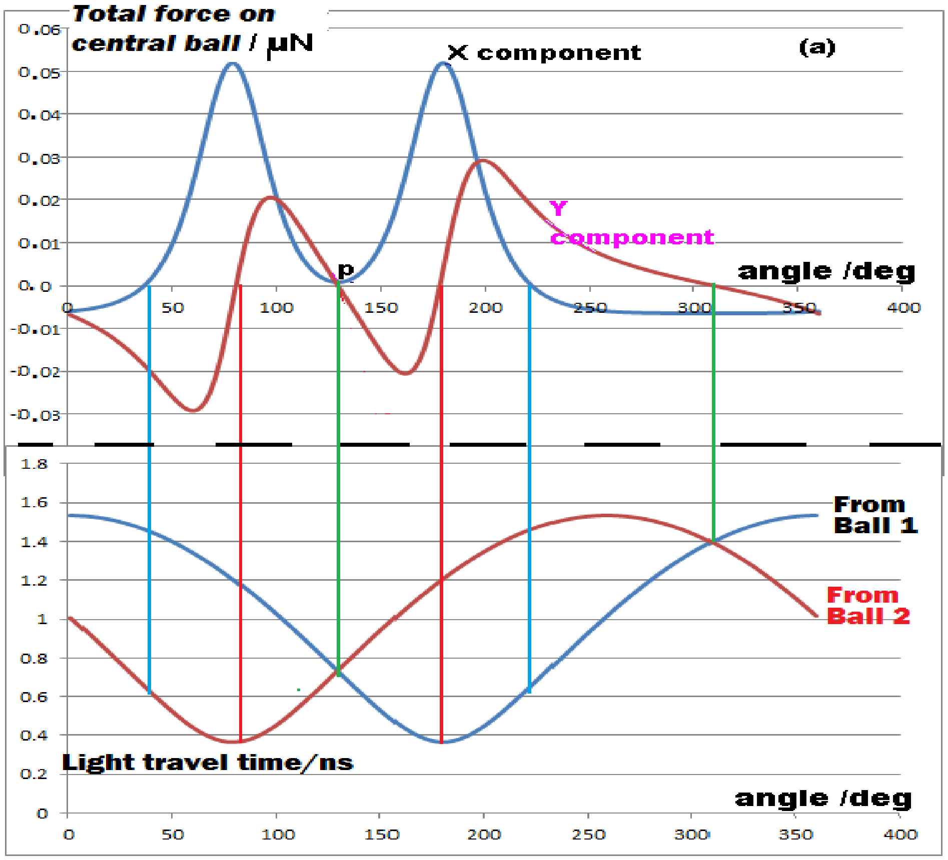


Figure 4 : Forces and light travel times. Green lines show where both balls are equidistant at force cancellation. Otherwise blue is for when the X component only is zero and red for the when the Y component only is zero.

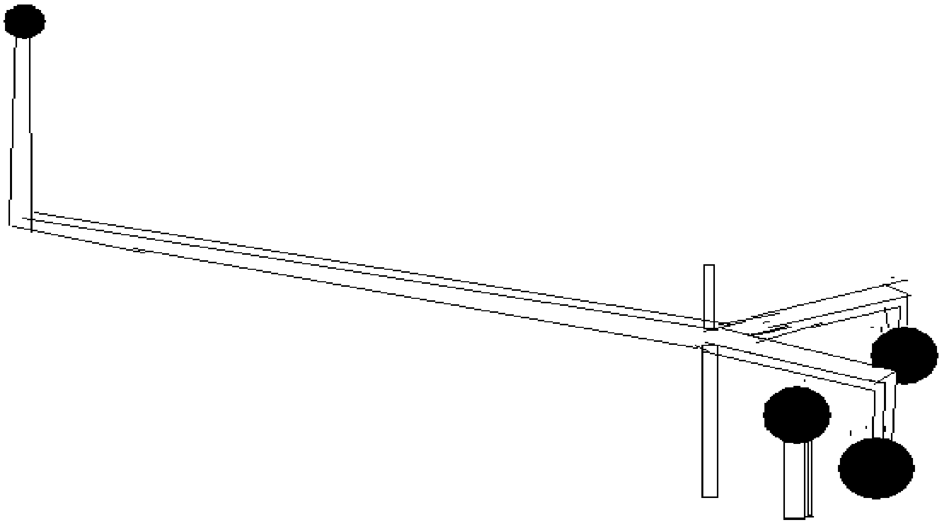


Figure 5 : Possible rotor system with distant counterweight.

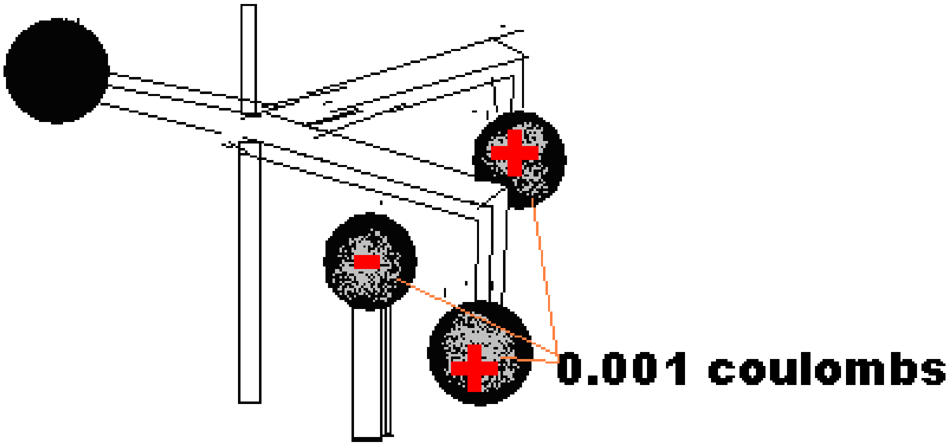


Figure 6 : Possible rotor system with three Van de Graaff generators to measure the speed of the Coulomb force.

Note again that a distinction should be made between the speed of electromagnetic waves, which is c, and the speed of propagation of the force. It would be another proof of QED if the latter speed were also c. Also, the proposed static set-up of Figure 7 should be much easier and cheaper than the other experiments made to measure V (Coulomb) as proposed in[6] and carried out in[8] (the latter using high-energy electron beams).

Related to the speed of the Coulomb force is the speed of the magnetic force. The speed at which the magnetic force, created by pulsing an electromagnet, propagates to affect a target sensor can possibly be measured. Though this experiment also needs high precision, it is also well within the range of modern technology.

For example, a coil with 1,000 turns of 0.5 mm diameter copper wire can give, for 10A (10,000 A-turns) and a coil radius of 3cm, 0.2 T at its center and at 100 m a field of 5.65 nT (Figure 8). Modern probes can measure with this accuracy. Squid sensors can measure down to fT. If the set-up is in a shielded magnetic 'clean-room' then only the field from the pulse will register and it will be possible to determine the speed of transit. For 100 m light travel time is 0.3 micro-sec. With a micro-sec pulse of current in the coil it should be possible to determine the travel time accurately enough to test the hypothesis that B speed could be faster than light. The coil resistance in the above example is about 15 ohm. A micro-sec pulse of 100A then gives 100,000 A-turns and a power of 150 kW. But the short pulse time means only 0.15 J of energy is used. I.e. again the requirements in terms of energy and capital outlay, are relatively small for this experiment. This larger current then gives 56 nT, which should be even easier to measure.

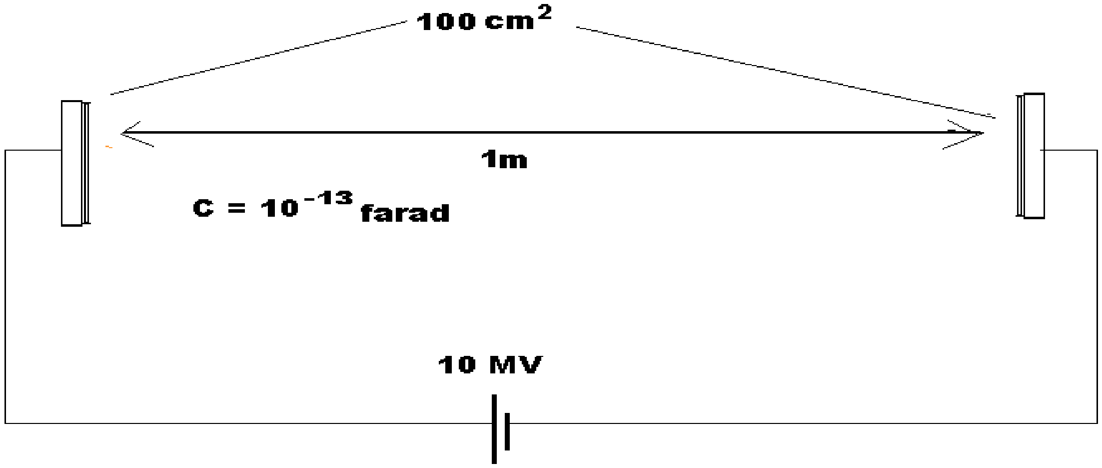


Figure 7 : Possible set-up with two large capacitor plates at a large distance of 1 m, to measure the speed of the Coulomb force.

Regarding the implications if any of these forces were found to propagate at trans-luminal velocity, the most obvious practical application is to set up some system of FTL communication. Again, either the magnetic or coulomb systems are easiest to set up.

Whether the seeming immunity of these fields to the limitations of special relativity could be used for a FTL space drive or not, is another area of interest. I.e. the FTL speed of communication using EM fields indicates that a cocoon of such fields might somehow be used to convey material objects at a speed exceeding that of light. Possibly such a system of super-conducting, sandwiched layers as in Figure 9 could line the hull of a spacecraft. This could be combined with a few Casimir cavity layers. Such Casimir cavities have been suggested as a source of the 'negative energy exotic matter' needed for an Alcubierre drive. Such a construct could give the sort of negative energy layer needed for an Alcubierre type drive. The example shows a cross section through a toroidal system, with the crew in the inner toroid and coils generating the outer magnetic toroid. A superconducting layer on the outside of the crew quarters would prevent the inner toroidal magnetic field from entering the ship. The Casimir toroids would be suspended- possibly on magnetic cushions to prevent contact with normal matter.

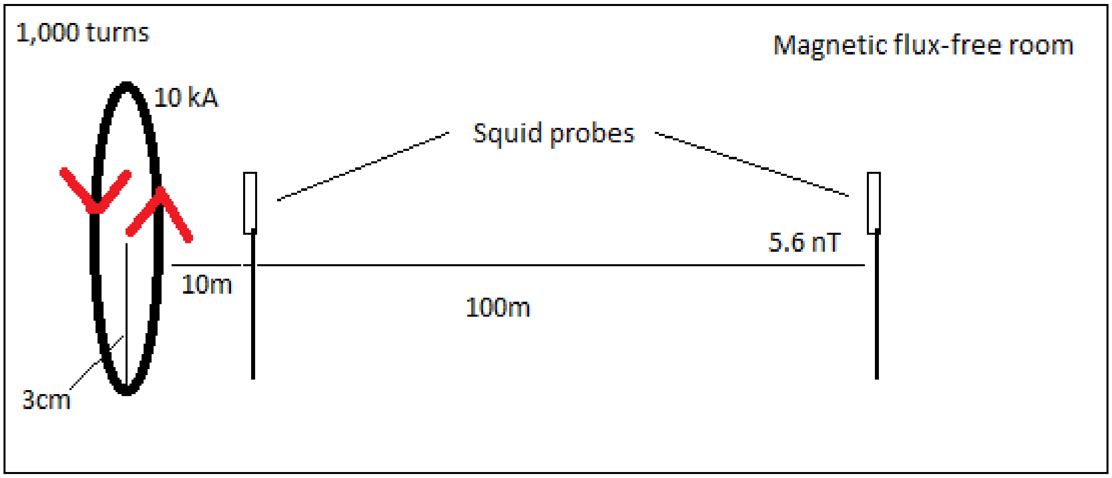


Figure 8 : Possible set-up with 1 coil of wire with 1,000 turns with squid probes, at a distance of 1m, to measure the speed of the magnetic force.

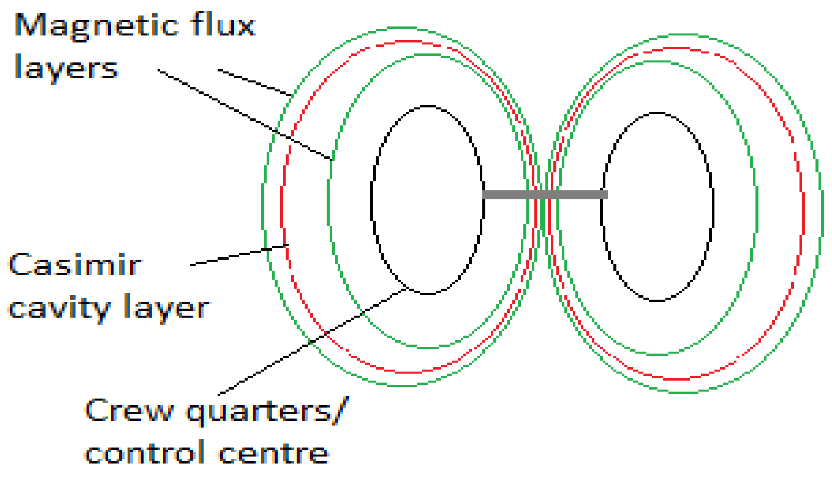


Figure 9 : Possible spaceship using successive layers of magnetic flux and Casmir cavities as shield from cosmic rays and as possible Alcubierre drive.

RELATED PRIOR WORK

As it is the easiest of the proposed experiments, it was decided to concentrate on the system shown in Figure 8 – i.e. measurement of the speed of the magnetic force in a laboratory setting. The basic coil is very cheap. The main expenses were in the pulse generator and the sensors. At time of writing, however, the system was still in preparation. Results should be forthcoming towards the end of 2014.

Since the experiment is still under construction, let us examine some other interesting results in this field. One study by Zhu[9] purports to show that lunar-solar gravity perturbations on geosynchronous satellite orbits lacks aberration. That is to say that the gravitational perturbing force comes from the 'true' positions of the moon and the sun and not their retarded positions as indicated by light rays. These calculations may be verified by independent replication of Zhu's calculations. It is hoped that other groups will do so and be able to confirm or refute the results of Zhu.

For the Coulomb force, we have already referred to the work by Calceterra et al.[8].

Again, it is hoped that others will try to replicate these results to test the hypotheses of luminal or super-luminal force propagation.

CONCLUSIONS, CONSEQUENCES AND FURTHER ACTIVITIES

An experiment has been proposed to measure the speed of gravitational interactions in a laboratory setting. State-of-the-art techniques in position measurement, timing and forces permit testing the hypothesis that the propagation occurs at the speed of light. A similar experiment may be done to measure the speed of the Coulomb force, though in this case the setup requires two large, stationary capacitor plates, or a standard coil and set of sensors.

The speed of the magnetic force could also be estimated, and would either corroborate or refute the results of Calcaterra et al[8].

The consequences for modern physics if these force speeds are shown to be super-luminal is that the light speed limit of relativity, though valid, may be limited to electromagnetic phenomena. That is, it may not apply to the purely electric, magnetic or steady-state gravitational forces where constant speeds are involved. This stands in no contradiction to the light speed limit as applied to gravitational waves due to accelerating masses or electromagnetic waves (which are due to accelerating charges).

The implications of these phenomena will be two-fold. First, they will require a re-assessment of the universality of the relativistic speed limit, which will lead to new physics. Secondly, some practical applications will arise based on these ideas. Most obvious is a faster-than-light (FTL) communication system. This could be useful in communicating with satellites around this or other planets. Also, for internet and computer internal data transfer, the implications could be considerable.

A possible application for interstellar travel could be to cocoon a vessel in layers of magnetic flux and Casimir cavities. Though highly speculative, a system of this sort could possibly give a sort of Alcubierre drive. If used together with the proposed *EHT*[10] drive, this could ensure that the mechanism envisaged there for interstellar travel is more certain to create the 'warp' conditions needed for a ship composed of electromagnetic matter to move with apparently FTL speed though interstellar space.

The new physics of *EHT* with its gravito-photons can be used as the propulsion system, while the magneto-Alcubierre cocoon could ensure that the spaceship, with its effectively cancelled inertia from the gravito-photon impulse, does not feel the motion through space as normal matter would. That is, the cocoon and the ship inside would be a form of 'exotic' matter. The combination of all these effects may allow the long awaited interstellar drive to become a reality. Note that if the magnetic, electric and gravitational fields on their own are found to act in a super-luminal manner, this again implies that GR is incomplete and that new physics are needed for a complete description of nature. The EHT framework offers new physics that may be consistent with these phenomena as well as with the large gravito-magnetic forces tentatively measured by Tajmar et al.[11].

The next step will be to try to replicate the speed measurements of the electric and/or magnetic forces from the work of others. If the light speed limit is found not to be operative in this case, we will then try to build a prototype communication device based on these systems. If this technology becomes a reality, then the new physics associated with it will become more prominent. If propulsion technology becomes another result of these effects coupled to the propulsion predictions of *EHT*, then even more new physics will have to be considered by the scientific community.

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