Comments on Will's Theoretical Interpretation of the Kreuzer Experiment

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Abstract

In 1966, the Kreuzer experiment sets an upper limit on the difference in the ratio of active to passive mass between fluorine and bromine, and an interesting interpretation was given by Thorne et al. However, in 1976 Will, with his new parametrized post-Newtonian (PPN) approach, interpreted this experiment as providing an upper limit on his parameter combination related to electromagnetism. It is shown that, from the viewpoint of general relativity, Will's approach remains to be justified. Moreover, his result is originated from his unphysical nucleus model which ignores the isospin dependent nuclear forces and is actually inconsistent with general relativity. It seems that to determine the constraint on the gravitational coupling to electromagnetism, would be beyond the valid application of the PPN formalism. As a further step, experimental measurement for the coupling constant to electromagnetism is recommended.

Comments on Will's Interpretation of the Kreuzer Experiment

1. Introduction.

The Kreuzer (1966) experiment sets an upper limit of 5 parts in 10^5 on the difference in the ratio of active to passive mass between fluorine and bromine. Because of the atomic structure of matter, naturally attempts were made to interprete the Kreuzer experiment as a test of the manner in which different forms of matter and energy generate gravity. Thorne et al. (1971) made an interesting interpretation by using the perfect-fluid Parametrized Post-Newtonian (PPN) formalism. However, Will (1976) claims that , based on mass equivalence alone, it is possible to extend a PPN formalism so as to have a reliable study of the generation of gravity by electromagnetism due to different nuclei.

In this paper, it will be shown that Will's nucleus model and his theoretical interpretations are not valid because they are based on unverified assumptions which are actually inconsistent with general relativity and other established theories. From the viewpoint of general relativity, unlike the case of Nordtvedt's PPN formalism, energy-mass equivalence may not be assumed in Will's PPN "extension". In summary, Will's calculation is not justified (see also § 4).

General relativity is a theory which abandoned naive visualization in favor of a conceptual analysis. Consequently, the physical meaning of general relativity can be obscured by prejudice. To see why Will's (1976) analysis is not valid, one should get to the root of his problem, some incorrect beliefs due to misunderstanding relativity. They include:

1) Any type of energy is equivalent to mass. According to general relativity, this is simply not true. Because the source term in the Einstein equation is an energy-stress tensor instead of just energy (Weinberg 1972; Yu, 1989), the energy-mass equivalence is restricted. For example, the electromagnetic energy and mass are not equivalence since an electromagnetic stress tensor is traceless. This has been explicitly manifested by the Reissner-Nordstrom metric (Misner, et al. 1973; Wald, 1984),

$$ds^2 = (1 - \frac{2M}{r} + \frac{q^2}{r^2})dt^2 - (1 - \frac{2M}{r} + \frac{q^2}{r^2})^{-1}dr^2 - r^2 d\Omega^2, \quad (1)$$

where q and M are the charge and mass of a particle and r is the radial distence from the particle. Note that, in metric (1), the gravitational components generated by mass and electricity have different signs and furthermore very different radial coordinate dependence. Nevertheless, this non-equivalence remains compatible with Einstein's famous equation on the total energy,

$$E = m\ c^2. \quad (2)$$

It is crucial to note that E is the *total* energy of a particle or a system of particles. In an atom, the total energy includes at least the nuclear energy; and the related electromagnetic energy is comparatively small. Thus, general relativity also requires the verified fact, a small isospin dependence of the nuclear force.

2) Extended universal coupling is valid for any form of energy-stress tensor. Whereas Newtonian universal coupling for massive matter has its ground on atomic structure; the extension of this coupling to other forms of energy is unverified. In 1931, Pauli (1958) pointed out that general relativity does not provide a physical interpretation for the sign and numerical value of the gravitational coupling constant. Recently, the necessary existence of anti-gravity coupling is discovered and verified (Lo, 1991; 1995). Thus, extended universal coupling is not generally valid.

3) General relativity is only a more accurate modification of Newtonian gravity. This creats a illusion that any problem can be deal with an improved post-Newtonian approximation. General relativity is a revolution in the theory of gravity although linearized gravity projects an image of evolution. (It should be noted that linearized gravity was found to be unreliable by Einstein (Born, 1968) himself; and this has been confirmed by Lo (1994).) For instance, if mass-energy equivalence is assumed, Nowtonian theory would imply that an electromagnetic plane wave could generate an infinitely divergent gravitational potential because the electromagnetic energy, on the average, is a constant. However, the approximate validity of classical electrodynamics and special relativity requires that such a potential is not only finite but also bounded as general relativity implies (Lo, 1991). Thus, the PPN formalism may not be generally applicable to weak gravity.

Obviously, Will's approach is grounded on 3). To justify 2) for electromagnetism, a crucial assumption of Will's analysis is 1).

Nordtvedt's PPN formalism for particles is essentially based on the model of a gas of neutral mass elements (see Appendix A). When non-gravitational interactions are also considered, an extension is essential based on the implicit assumption, the equivalence between internal-energy and mass. Such an assumption is supported by experiment and is probably necessary for general relativity. However, this may not imply extended universal coupling since only the question of an appropriate coupling for each type of energy-stress tensor has been circumvented.

If gravity of matter is due to the resulting mass, general relativity must require some cancellations among gravitational effects from different types of energy in matter since electromagnetism violates mass-energy equivalence. However, this also mean that PPN formalism would be valid if, for each particle, only the final total of different energies is involved. Then, there will not be new PPN coefficients for each type of interaction as in Will's approach. Nevertheless, from Nordtvedt's fundamental, model independent, metric field expansion, one can go to PPN potentials proportional to pressure densities, internal energy densities etc. if one wishes (see Appendix A).

2. Will's Approach and Results.

Without a valid justification, Will (1976) superficially extended Nordvedt's (1968) PPN framework for the purpose of including the coupling effects of interactions of the point particles (i.e. nucleons) via electric Coulomb fields and additional parameters. Then, in addition to Nordtvedt's point-mass potentials, this extended formalism includes three new "electric" gravitational potentials and their associated PPN parameters ε_1, ε_2 and ε_3. Thus, there are 11 parameters -- γ, β, ζ_1, ζ_2, ζ_w, α_1, α_2, α_3, ε_1, ε_2 and ε_3. For a body in which the distribution of particles is spherical, Will claims that the active mass m_A and inertial mass m_I are related by

$$m_A = m_I + (4\beta - \gamma - 3 - 2\zeta_2 - 2\zeta_w - \frac{1}{2}\alpha_3 - \frac{1}{3}\zeta_1)\Omega^*$$

$$+ (\varepsilon_1 + \frac{1}{3}\varepsilon_2 - \frac{1}{2}\alpha_3 - \frac{1}{3}\zeta_1)\Omega_E^*,$$

where

$$\Omega^* = -\frac{1}{2}\sum_{i\neq j}\frac{m_i m_j}{|\mathbf{x}_i - \mathbf{x}_j|}, \quad \Omega_E^* = \frac{1}{2}\sum_{i\neq j}\frac{e_i e_j}{|\mathbf{x}_i - \mathbf{x}_j|}, \qquad (3a)$$

where m_i, e_i, and $\mathbf{x}_i$ are the rest mass, charge, and position of the ith particle (the speed of light and Newtonian gravitational constant are chosen as unity). Will assumes that the passive mass $m_P = m_I$ is justified by Eötvös (1922) experiments. Will further assumes that

$$|\Omega^*| << \Omega_E^* . \qquad (3b)$$

Finally, in comparison with Kreuzer's experiment, Will obtains an upper limit on his PPN parameter combination:

$$|\varepsilon_1 + \frac{1}{3}\varepsilon_2 - \frac{1}{2}\alpha_3 - \frac{1}{3}\zeta_1| < 3 \times 10^{-2} . \qquad (4)$$

Thus, in violation of general relativity, Will obtained a relation based on the dubious equivalence of mass and elctromagnetic energy. Therefore, the validity of eq. (3a) should be examined. It will be shown that Will uses unverified and invalid assumptions, and the related calculations are also problematic. In fact, Will's theory may not even be self-consistent (see also Appendix A).

3. Questions Related to Nuclear Energy.

For a probem related to the structure of nuclei, it is inconceivable that the nuclear energy is not considered. On the other hand, due to our limited knowledge in nuclear physics, one should expect that little tangible result would be obtained if the nuclear force has to be accurately accounted for. In view of this, natually one would attempt to circumvent our ignorance concerning nuclei. The problem is that, in terms of physics, Will's circumvention is not valid.

Will (1976) claimed that his model of a nucleus is a gas of electromagnetically interacting particles in a square-well nuclear potential. However, in calculation he actually assumes that the nuclear energy-stress tensor has no (or at least negligible) gravitational effects. This is evident since there is no "nuclear" PPN potentials in his metric,

$$g_{00} = 1 - 2U^* + 2\beta U^{*2} - (2\gamma+1+\alpha_3+\zeta_1)\Phi_1^* - 2(1-2\beta+\zeta_2)\Phi_2^*$$

$$+ 2\zeta_w\Phi_w^* + \zeta_1 A^* - (1+\gamma+\varepsilon_1)E_1^* + \varepsilon_2 E_2^* + \frac{1}{2}(1+\gamma+\varepsilon_3)E_3^* ,$$

$$g_{0\alpha} = \frac{1}{2}(4\gamma+3+\alpha_1-\alpha_2+\zeta_1)V_\alpha^* + \frac{1}{2}(1+\alpha_2-\zeta_1)W_\alpha^*,$$

$$g_{\alpha\beta} = -\delta_{\alpha\beta}(1+2\gamma U^*), \tag{5a}$$

where

$$U^* = \sum_i \frac{m_i}{r_i}, \quad \Phi_1^* = \sum_i \frac{m_i v_i^2}{r_i}, \quad \Phi_2^* = \sum_i \frac{m_i}{r_i} \sum_{j \neq i} \frac{m_j}{r_{ij}},$$

$$\Phi_w^* = \sum_{ij \neq i} \frac{m_i m_j \mathbf{r}_i}{r_i^3} \cdot \left(\frac{\mathbf{r}_{ij}}{r_j} - \frac{\mathbf{r}_j}{r_{ij}}\right), \quad A^* = \sum_i \frac{m_i [\mathbf{v}_i \cdot \mathbf{r}_i]^2}{r_i^3}$$

$$E_1^* = \sum_i \frac{e_i}{r_i} \sum_{j \neq i} \frac{e_j}{r_{ij}}, \quad E_2^* = \sum_{ij \neq i} \frac{e_i e_j \mathbf{r}_{ij} \cdot \mathbf{r}_i}{r_{ij}^3 r_i}, \quad E_3^* = \left[\sum_i \frac{e_i}{r_i}\right]^2, \tag{5b}$$

where v_i^α is the velocity of the *i*th particle and where

$$\mathbf{r}_i = \mathbf{x} - \mathbf{x}_i, \; r_i = |\mathbf{r}_i|, \; \mathbf{r}_{ij} = \mathbf{x}_i - \mathbf{x}_j, \; r_{ij} = |\mathbf{r}_{ij}|. \tag{5c}$$

Note that, in principle, the potentials in metric (5) do not agree with Nordtvedt's PPN formalism (see Appendix A). This is not surprising since Will's approach is in disagreement with general relativity.

The implicit assumption is manifested again in the following stress-energy tensor for matter and non-gravitational fields,

$$T^{ab} = (-g)^{-\frac{1}{2}} \sum_i m_i \delta(x-x_i) u^a u^b / u^0 - \frac{1}{4\pi}(F^a{}_c F^{bc} - \frac{1}{4} g^{ab} F_{cd} F^{cd}). \tag{6}$$

Note that, according to general relativity, a square-well nuclear potential should have an energy-stress tensor since a source tensor must be consistent with the equation of motion. As a consequence of eq. (6), the equation of motion includes only the Lorentz force and the gravitational force as follows:

$$m_i\ u_i{}^b\ u_i{}^a{}_{;b} = -\ e_i\ F^a{}_b(x_i)\ u_i{}^b\ , \tag{7}$$

Using the Newtonian virial theorem superficially, Will (1976) obtained a non-physical equation as follows,

$$\sum_i m_i v_i{}^2 + \Omega^* + \Omega_E{}^* = 0\ . \tag{8}$$

Eq. (8), which is inconsistent with eq. (3b), is clearly not valid if one considers the numerical ratio between protons and neutrons in a nucleus and the coupling strength ratio between gravitational and electromagnetic interactions. The root of this problem is that the virial theorem (Goldstein, 1980) does not actually imply eq. (8).

In order to be formally consistent in mathematics, Will assumes that the inertial mass m_I takes the following form

$$m_I = \sum_i m_i + \frac{1}{2} \sum_i m_i v_i{}^2 + \Omega^* + \Omega_E{}^* \tag{9}$$

where

$$\Omega^* = -\frac{1}{2} \sum_{i \neq j} \frac{m_i m_j}{|x_i - x_j|}\ , \quad \Omega_E{}^* = \frac{1}{2} \sum_{i \neq j} \frac{e_i e_j}{|x_i - x_j|}\ ,$$

Now, although it is well-known that the bounding energy for a nucleus is negative, according to eq. (9), this also does not seem to be possible. Note that eqs. (8) and (9) are crucial for eq. (3).

It should be pointed out that even Will's "square-well" model is not adequate for gravity problems. Such a model requires at least the nuclear energy is independent of the charges. A completely isospin independence of nuclear energy is not supported by nuclear physics (Blatt et al., 1952). Because of the large magnitude of the nuclear energy, a small isospin dependence would imply a validity problem for Will's model.

Will (1976) argued, in an attempt to defend the absence of nuclear forces in his model, that nuclear forces could be incorporated properly by introducing "Nuclear" PPN potentials into the metric (5). He mentioned that he could use potentials generated by Yukawa forces. However, first, it is not clearly possible to develop meaningful PPN potentials of his (such that the resulting PPN formulism can encompass general relativity). Note that general relativity implies that gravity depends not only on the energy but also the energy form since the source is a tensor in Einstein equation. Moreover, Yukawa forces are not exact, but approximations. Now, it is clear that mass equivalence alone is inadequate. Given the vast magnitude differences between nuclear and electromagnetic energies, considering that nuclear energy is isospin dependent, it does not seem possible that the so developed formula is also the same eq. (4). Note that, in deriving eq. (4) from eq. (3a), a crucial argument is that the term related to Ω^* is negligible. But, in comparison with the electromagnetic energy Ω^*_E, nuclear energy is certainly not negligible.

If gravity of matter is due to the resulting mass, general relativity would require some cancellations among gravitational effects, in particular those violate mass equivalence, from different types of energy in matter. For a nucleus, this would mean that the violation due to electromagnetism should be cancelled out by the gravitational effect due to other interactions such as the nuclear interaction etc. Thus, in connection with considering violation of mass equivalence for a nucleus, it is difficult to justify, in violation of general relativity, that the gravitational effect of electromagnetism be considered isolately as in Will's approach.

In short, according to general relativity, Will's formalism cannot be justified. Moreover, Will's calculation is not valid because nuclear forces, which are isospin dependent, are unjustifiably ignored.

4. Conclusion and Discussion.

In the PPN formalism (Misner et al., 1976), the source tensor is essentially for massive matter. The tensor parts related to the total internal energy have a specific form which can be easily incorporated into the mass density. However, it is not necessary and would be difficult to justified that each type of internal-energy is compatible with such a form. (The non-equivalence between mass and the electromagnetic energy is also manifested by the fact that the photons have no rest mass.) This means that there should be cancellations among gravitational effects due to different types of energies. Thus, in the PPN formalism, the coefficient of a potential related to a type of internal energy would be related to a combination of (instead of a single) coupling constants. Obviously, such cancellations are excluded in Will's new approach. Apparently, Will's goal is to justify the extension of Newtonian universal coupling. But, since he has to use so many incorrect asumptions in his "analysis", the result is probably the opposite.

As pointed out by Pauli (1956), general relativity is, in principle, compatible with the notion that, for a different type of energy, there can be a different coupling constant. In the PPN formalism, it seems that there is only one coupling constant. The reason is that essentially only the energy-stress tensor for massive matter is considered. Although there are other types of internal energies, the problem of possibly different coupling constants has been circumvented by the necessary cancellations discussed earlier.

General relativity is, in principle, incompatible with a massive point-particle because that implies an infinitely concentrated mass. Therefore, from the viewpoint of general relativity, a point-particle model should be justified, for instance, as the limit of a dust model. (One might argue that a continuum picture no longer applies at atomic and nuclear dimension. But, this does not imply that a continuum model for a particle is not valid. Note that Einstein (1919), among other physicists, studied a continuum model for the electron.) However, a dust model implies that there are little interactions among different parts of a particle. This is incompatible with the fact that in nature stable massive particles are strongly bounded together. On the other hand, a perfect fluid model for a charged particle (such as the electron) could mean a much larger coupling constant for electromagnetism. Since Will (1976) considers that his parameters are individually related to a coupling constant, this model dependence of a coupling would mean model dependence of Will's formalism.

It has been concluded that, from the viewpoint of general relativity, Will's (1976) results and approach are problematic. Moreover, in principle, it does not seem possible to use Nordtvedt's formalism to examine its implicit assumption of energy-mass equivalence. Nevertheless, Will (1976) has inadvertently addressed a meaningful question, whether the coupling to electromagnetism is the same as that to massive matter since energy and mass are not completely equivalent.

It should be noted that the question of extending universal coupling to electromagnetism is important to theoretical physics. For instance, this extension seems to be the only theoretical basis for the assumption of a compact fifth dimension (Klein, 1926). This in turn is a foundation for the current even higher dimensional theories (Green, 1982). Thus, it may be crucial to verify this extended universal coupling by experiment. In view of the complication due to nuclear energy, it may be necessary first to obtain the gravity effect of electromagnetism from an experiment on gravitational effects due to electromagnetic energy only. To this end, in principle one can measure, for example, the accompanying gravitational wave of an electromagnetic wave.

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Appendix A: Nordtvedt's PPN Formalism and Will's Theory.

In this appendix, it is pointed out that Will and Nordtvedt actually have very different understanding of the PPN formalism although they both wrote extensively on PPN formalism and moreover two papers together. In Nordtvedt's formalism, the question of coupling constant for each particular type of energy-stress tensor can be cleverly circumvented; whereas Will attempts to address the question of coupling constants with his PPN formalism. To identify problems in Will's (1976) approach, it would be useful to give a brief description of the original PPN formalism for point-like particles.

Nordtvedt's PPN formalism is based on the model for a gas of neutral mass elements (Nordtvedt, 1992). For illustration purpose, it would be sufficient to write down the time-time component of the metric,

$$g_{00} = 1 - 2\sum_i \frac{m_i}{r_i} + 2\beta \sum_{ij} \frac{m_i m_j}{r_i r_j} + 2(2\beta - 1)\sum_{ij} \frac{m_i m_j}{r_i r_{ij}}$$

$$- (2\gamma + 1)\sum_i \frac{m_i v_i^2}{r_i} + \ldots \qquad \text{(A1)}$$

This model must be consistent under dissecting each neutral mass element and adding the non-gravitational forces which participate in holding the mass elements and composite bodies together since such energies contribute to the resulting mass. We know that we must have the kinetic term shown. That leads the way in inferring the unique structure for this metric field component which would be model independent. The above metric field expansion must, in Nordtvedt's view, have the following form in order to have consistency under dissection;

$$g_{00} = 1 - 2\sum_i \frac{m_i + t_i + \frac{1}{2} u_{ij}}{r_i} + 2\beta \sum_{ij} \frac{m_i m_j}{r_i r_j} + 2(2\beta - 1) \sum_{ij} \frac{m_i m_j}{r_i r_{ij}}$$

$$- 2\gamma \sum_i \frac{m_i v_i^2 + f_{ij} * r_i}{r_i} + \ldots \qquad \text{(A2)}$$

where t_i is kinetic energy of the matter elements, u_{ij} is all forms of non-gravitational interaction energy and the vector f_{ij} includes all non-gravitational forces acting between the dissected particles making up the original total mass elements.

The source quantity now having the 2γ coefficient is the total non-gravitational scalar virial of the source matter. This metric expansion now gives for the total active gravitational mass of a body;

$$m_A = \sum_{ij} [m_i + t_i + \frac{1}{2} u_{ij} - \frac{1}{2} \frac{m_i m_j}{r_{ij}}] + (4\beta - 3 - \gamma) U_G$$

$$+ \gamma[(\text{virial})_{NG} + (\text{virial})_G], \qquad \text{(A3)}$$

where U_G is the gravitational self-energy of the body. The total virial multiplying the gamma term now vanishes for a body in internal equilibrium and isolated from tidal (or other) forces from the outside world. Then, the first factor is the total mass-energy of the body including both gravitational and all non-gravitational interactions. If the inertial mass m_I is equal to the total mass-energy, then for general relativity (since $\beta = \gamma = 1$) one has $m_I = m_A$.

Thus, in Nordtvedt's PPN formalism, energy-mass equivalence would be inherent. This is not difficult to understand because energy-mass equivalence is an implicit assumption for formula (A2). Since all such energies are effective masses, formula (A2) is a reasonable conjecture. Under such circumstances, this assumption of equivalence can be consistent with general relativity which implies that individual energy and mass may not be equivalent in terms of gravity. However, the validity of (A2) does not mean that the coupling constant is necessarily universal although there is no new PPN coefficients for each type of energies.

From the viewpoint of general relativity, in (A2) one deals with only the energy terms resulting from after the necessary cancellations among the gravitational effects from different types of energies. Thus, the question of an appropriate coupling constant for each particular type of energy is cleverly circumvented. Therefore, (A2) should not depend on the specific models of the energy-stress tensors in the source of Einstein equation. Note that all non-gravitational energy terms in (A2) can be considered as among particles, and there is no potential, which is related to pure field energy, such as E_3^* in Will's metric (5).

Will claims that his PPN formalism is a continuation of Nordtvedt's formalism. However, this seems to reflect a lack of understanding the physics of Nordtvedt's work. Although their formalisms may appear to be related, there are fundamental differences. First, since Will's PPN coefficients are related to coupling constants of energy-stress tensors, his formalism requires different justification and therefore may not be valid. Second, Will's formalism is no longer model independent because a coupling constant can depend on the model of an energy-stress tensor. A reason for this dependence is due to the necessary compatibility between the source tensor and the equation of motion. For example, a perfect fluid model for a charged particle (such as the electron) could mean a much larger coupling constant for electromagnetism.

From eq. (A3), it is clear that Kreuzer experiment implies a constraint on the coefficient of U_G (or Ω^* in Will's notation). It should be noted that eqs. (3a) and (3b) do not necessarily imply eq. (4) which requires an additional relation such as

$$|(4\beta - \gamma - 3 - 2\zeta_2 - 2\zeta_w - \frac{1}{2}\alpha_3 - \frac{1}{3}\zeta_1)\Omega^*| << |(\varepsilon_1 + \frac{1}{3}\varepsilon_2 - \frac{1}{2}\alpha_3 - \frac{1}{3}\zeta_1)\Omega_E^*|. \qquad \text{(A4)}$$

Thus, eq. (A4) would be another necessary implicit assumption. Eq. (A4) implies that there is no significant cancellation among the two terms although they may have different signs.

However, (A4) may not always be valid. According to Will (1976), a metric theory of gravity posses integral conservation laws for total momentum if and only if its point-mass PPN parameters satisfy

$$\alpha_3 = 0, \ \varepsilon_1 = 0, \ \varepsilon_3 = 0, \quad \text{and} \quad \varepsilon_2 = \zeta_1 = -2\zeta_2 = -2\zeta_W \qquad \text{(A5)}$$

Note that the relation, $\varepsilon_2 = -2\zeta_W$, implies the necessary cancellation of gravitational effects due to conspiracy among gravitational and electromagnetic potentials. Eq. (A5) implies that the coefficient of Ω_E^*,

$$\varepsilon_1 + \frac{1}{3}\varepsilon_2 - \frac{1}{2}\alpha_3 - \frac{1}{3}\zeta_1 = 0. \tag{A6}$$

But, the coefficients of Ω^* is

$$4\beta - \gamma - 3 - 2\zeta_2 - 2\zeta_w - \frac{1}{2}\alpha_3 - \frac{1}{3}\zeta_1 = 4\beta - \gamma - 3 - \frac{10}{3}\zeta_W, \tag{A7}$$

which is (except for the last term) almost identical to the coefficient of U_G in eq. (A3), and may not necessarily be zero. Thus, Will's theory may not be self-consistent.

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