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ELECTRO-GRAVITY ENTANGLEMENT

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ABSTRACT. One fundamental question is the connection between electrical and gravitational forces. We present a quantum entanglement model, with multiple discrete electrically charged wave-packets, that simulates gravitational attraction among them, where quantum states can have only two wave-packets with opposite charge polarities, with equal absolute values, while the rest remain neutral, relating those charges to gravitational masses. We present a thought experiment where neutrons are displaced by electric fields above the Schwinger limit, predicting their maximum possible corresponding displacement magnitudes and diminishments in their gravitational masses (with increments elsewhere), estimating an upper bound for the gravitational mass of each of those entangled wave-packets allegedly constituting those neutrons. Thus, the realization of the experiment could verify the predictions, but cannot necessarily falsify the model. The model's significance rests in hypothesizing entanglements in a classical mechanical property without violating the measurement independence postulate and in its possible applications for gravity simulations with quantum systems.

Keywords: unification, electro-gravity, entangled electric charges, quantum simulations.

INTRODUCTION

Quantum systems can simulate situations that are classically impossible, such as simulating N-body gravitational attraction with electric charges; we present an approach that differs from typical electrogravity theories (CHEW, 2021). We present an N-body model, where pairs of charges in quantum states have correlated opposite polarities, while the others remain neutral, so that they always attract without the need for an explicit classical mechanism, contrasting recent suggestions to explain the relation between electricity and gravity with a hydrodynamic analogy (BERBENTE and BERBENTE, 2020). In this way, our model is an entangled quantum system where charged discrete wave-packets (WPs) can simulate Newton's law of gravity by superposing all possible opposite polarity pair states (OPPS), where the WPs in each of those OPPS are attracted to the others by Coulomb's law, without being explicit about the

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correlating mechanism, regardless of their relative locations, as is already well known of quantum systems (HENSEN *et al*., 2015; SHALM *et al*., 2015). From the point of view of the many-worlds interpretation of quantum mechanics (VAIDMAN, 2020) (only as a pedagogical tool to expound upon the model), each of the mentioned charges is attracted to its opposite by the inverse square law in one "world", but in another, the same pair does not necessarily attract nor repel because one of those two, or both, are neutral. The superposition of all those "worlds" is an entanglement which will be referred to as the electro-gravity entanglement (EGE). The superposition of those OPPSs is equivalent to Newton's law of gravity if the WPs of that EGE are associated with gravitational mass (GM) as a function of the intrinsic charges that form the entanglement, which will be referred to as EG-charges. In the non-reduced EGE, there are as many "worlds" where a WP is positive as there are "worlds" where it is negative, that is, the global EG-charge (GEGC) of that WP is zero. Such a GEGC is defined as the addition of the intrinsic EG-charges in all of those "worlds". Reduction of the EGE by external interaction with only one of its WPs can change the zero GEGC of that WP, changing also necessarily the one of all the others, which ends up with GEGC polarity opposite to the one of that WP, whose absolute value of its GEGC is equal to the absolute value of the sum of the GEGC of the others. In our model, Newton's law of gravity is approximately a macroscopic EGE in a Galilean reference frame, that is, in situations that don't require the theory of relativity, but it is not to say that the model cannot be generalized.

As shown in the methods section, decreasing the number of WPs in the EGE implies an increment in the average magnitude of the force attracting any entangled WP to the others. The average magnitude of such a force depends on the probability that both are in one of the aforementioned OPPSs. However, if the number of entangled WPs decreases, the average magnitude of that force increases due to the increment in the probabilities of all OPPSs resulting from fewer state elements forming a reduced EGE. The latter statement can also be interpreted as an increment in the GMs of those WPs. Given the necessity to introduce new relevant paradigms (DODELSON, 2011; CHAE *et al*., 2020; CHAE, 2022) based on cosmic evidence, our model could also be relevant. Based on our model, GM increments in a whole system can be associated with diminishments in the GM of particular WPs that are not part of that system under consideration. Models suggested in the literature do not acknowledge the possibility of the macroscopic EGE introduced in the present work.

If gravity results from an EGE then the GMs of a set of WPs forming the EGE could be displaced by an external electric field. We present the equation that predicts all the possible values of *effective* EG-charge for sets of "attached" WPs forming known elementary "particles": such an effective EG-charge behaves just like an ordinary charge when interacting with an external electric field. The maximum value of effective EG-charge predicted can be tested to confirm our model with neutrons.

We offer a thought experiment with neutrons (n^0) moving through a homogeneous electric field. Our calculations imply an effective EG-charge

$$q^{eff} = \zeta(|A|, \eta) \cdot m_a \sqrt{\frac{G}{K}} \tag{1}$$

(a similar relation has been mentioned in the literature by others (CLAGUE, 2022; DUNCAN, 2023) in a different context without the EGE and its implications), where K and G are the Coulomb's constant and gravitational constant, respectively, and m_a is the smallest GM possible. We hypothesize that $m_a < 1.424 \times 10^{-36}$ kg, based on the latest estimate for the neutrino's (ν) rest mass (FORMAGGIO *et al*., 2021; VAYANAS *et al*., 2021; AKER et al., 2022) assuming that such a mass is attracted by Newton's inverse square law to other GMs. Such an upper bound is also used to calculate the output of the function $\zeta(|A|, \eta)$ for inputs corresponding, respectively, to a lower bound for the number of WPs in a neutron, and a parameter $\eta_{max} = |A|/2 - 1$ that results in the maximum possible effective EG-charge with that lower bound. Our calculations imply an upper bound of 4.044×10^{-51} C for the maximum possible effective EG-charge of a neutron. In the thought experiment presented, the effective EG-charge can be detected by allowing neutrons to separate freely from their original paths, for a time that allows to distinguish those separations from their quantum uncertainties, after interacting impulsively with the homogeneous electric field that provides momentum to each neutron. Our results show that a field greater than 1×10^{25} N/C is required to make a detection with the parameters introduced for the thought experiment.

METHODS

Axioms for the model and the implications

In a Galilean reference frame, N WPs that belong to

$$\left\{\psi_n^{(\phi_n)} |\ \phi_n \in \{0, +|q_n|, -|q_n|\};\ \forall n \in \{N\}\right\},$$

having electric charge values specified by ϕ_n, forming elementary "particles" that satisfy Schrodinger's equation, are part of

$$U = \left\{|\psi_1^{(0)}, \psi_2^{(0)} \dots, \psi_a^{(\pm|q_a|)}, \dots, \psi_b^{(\mp|q_b|)}, \dots, \psi_N^{(0)}\rangle\ |\ \forall a, \forall b \in \{N\}; b \neq a\right\} \tag{2}$$

such that any $|\Lambda_{q_a,q_b}\rangle \in U$, with those two discrete opposite polarity *intrinsic* EG-charges q_a and q_b that have equal absolute values while the others are zero, satisfy orthonormality condition

$$\left\langle\Lambda_{q_a,q_b}\middle|\Lambda_{q_a',q_b'}\right\rangle = \delta_{q_a,q_a'} \cdot \delta_{q_b,q_b'} \tag{3}$$

in the following axioms:

Axiom 1: The average electric force on a WP a by b, due to their intrinsic charges, is $\vec{\boldsymbol{f}}_{ab}$, such that

$$\vec{\boldsymbol{f}}_{ab} = P_{ab}\langle\Lambda_{q_a,q_b}|\ \widehat{\boldsymbol{F}}_{nm}|\Lambda_{q_a,q_b}\rangle\, \hat{r}_{ab}, \tag{4}$$

where the linear operator

$$\widehat{\boldsymbol{F}}_{ab}|\Lambda_{q_a,q_b}\rangle = \left|\vec{\boldsymbol{f}}_{ab}^{(\lambda)}\right| \cdot |\Lambda_{q_a,q_b}\rangle, \tag{5}$$

and where P_{ab} is the probability that a and b have charge q_a, q_b. The average force is in the direction of the unit vector $\hat{r}_{ab}$ pointing from the average position of b towards that of a. Similarly, the average force on any WP a by an *external* electric field $\vec{\boldsymbol{E}}_l$ (such as the one from an electron or proton) is

$$\vec{\boldsymbol{f}}_{al} = P_{q_a} q_a \vec{\boldsymbol{E}}_l, \tag{6}$$

where P_{q_a} is the probability that a has charge q_a.

Axiom 2: Matter form the orthonormal state $|EGE\rangle_N$ that consists of the superposition of all possible $|\Lambda_{q_a,q_b}\rangle \in U$, forming a complete set, that is,

$$|EGE\rangle_N = \sum_a^{N-1}\sum_{b>a}^{N}\left(\sqrt{P_{+|q_a|,-|q_b|}}\ |\Lambda_{+|q_a|,-|q_b|}\rangle + \sqrt{P_{-|q_a|,+|q_b|}}\ |\Lambda_{-|q_a|,+|q_b|}\rangle\right) \tag{7}$$

such that

$$\sum_a^{N-1}\sum_{b>a}^{N}(P_{+|q_a|,-|q_b|}+P_{-|q_a|,+|q_b|})=1. \tag{8}$$

Such a completeness condition is also true for the state-elements of any reduction of $|EGE\rangle_N$.

Axiom 3: The GM of $\psi_a^{(\pm|q_a|)}$, in *Axiom 2*, attracted by $\psi_b^{(\mp|q_b|)}$, is a function of both $|q_a|$ and the probability $P_{\pm|q_a|,\mp|q_b|}$ as defined in *Axiom 1* and used in *Axiom 2,* that is,

$$m_a = |q_a|\sqrt{P_{+|q_a|,-|q_b|}+P_{-|q_a|,+|q_b|}}\sqrt{\frac{K}{G}}, \tag{9}$$

where m_a is that GM associated with $\psi_a^{(\pm|q_a|)}$, K is the electric constant in Coulombs law, and G is the gravitational constant.

For simplicity, the subscripts of $P_{\pm|q_a|,\mp|q_b|}$ and $|\Lambda_{\mp|q_a|,\pm|q_b|}\rangle$ will be written often just as $P_{\pm a,\mp b}$ and $|\Lambda_{\mp a,\pm b}\rangle$. Occasionally, $P_{ab}=P_{\pm a,\mp b}$.

The three axioms imply Newton's law of gravity. Consider only the intrinsic EG-charges of the WPs i and j such that $i,j\in\{N\}$. Notice that from *Axiom 1* and *Axiom 2* follows that

$$\vec{\boldsymbol{f}}_{ij}=\frac{P_{+i,-j}\cdot K\cdot(+)|q_i|\cdot(-)|q_j|}{|\vec{r}_{ij}|^2}\cdot\hat{\boldsymbol{r}}_{ij}+\frac{P_{-i,+j}\cdot K\cdot(-)|q_i|\cdot(+)|q_j|}{|\vec{r}_{ij}|^2}\cdot\hat{\boldsymbol{r}}_{ij} \tag{10}$$

if we regard $|\vec{\boldsymbol{r}}_{ij}|$ as the average distance between those two WPs. Then, assuming $P_{+i,-j}=P_{-i,+j}.\ and$ plugging q_i and q_j in terms of the GM in *Axiom 3,* implies

$$\vec{\boldsymbol{f}}_{ij}=-\frac{Gm_im_j}{|\vec{r}_{ij}|^2}\cdot\hat{\boldsymbol{r}}_{ij} \tag{11}$$

where the negative sign originates from the product of opposite charge polarities. Now, for two macroscopic objects, A and B, composed of WPs $a\in A, a\notin B, b\in B, b\notin A$, the force on A by B is the sum of all the forces on any a by any b, that is,

$$\vec{\boldsymbol{f}}_{AB}=\sum_{a=1}^{|A|}\sum_{b=1}^{|B|}\left(\frac{P_{+a,-b}\cdot K\cdot(+)|q_a|\cdot(-)|q_b|}{|\vec{r}_{ab}|^2}\cdot\hat{\boldsymbol{r}}_{ab}+\frac{P_{-a,+b}\cdot K\cdot(-)|q_a|\cdot(+)|q_b|}{|\vec{r}_{ab}|^2}\cdot\hat{\boldsymbol{r}}_{ab}\right), \tag{12}$$

applying *Axiom 1* and *Axiom 2* to each possible pair and adding them. The masses of A and B are

$$M_A=\sum_{a=1}^{|A|}|q_a|\sqrt{P_{+a,-b}+P_{-a,+b}}\sqrt{\frac{K}{G}} \text{ and } M_B=\sum_{b=1}^{|B|}|q_b|\sqrt{P_{+a,-b}+P_{-a,+b}}\sqrt{\frac{K}{G}}; \tag{13}$$

one can verify that that a macroscopic object A is attracted by B with a force

$$\vec{\boldsymbol{f}}_{AB}=-\frac{GM_AM_B}{|\vec{r}_{AB}|^2}\cdot\hat{\boldsymbol{r}}_{AB}, \tag{14}$$

considering only components in the direction of $\hat{\boldsymbol{r}}_{AB}$ and $\vec{\boldsymbol{r}}_{AB}$ connecting their centers of mass, given that $P_{+a,-b}=P_{-a,+b}$.

To test whether gravity is indeed an EGE, we first calculate the average force between any of the WPs in a "non-attached" sample set A (in the state described in *axiom 2*) by an external electric field (such as the one by an electron or a proton), such that $|A|\ll N$. In general, for all $a\in A$ and $a'\notin A$,

$$|EGE\rangle_N=\sum_{a=1}^{|A|}\left(\sqrt{P_{+|q_a|}}\,|\Omega_{+|q_a|}\rangle+\sqrt{P_{-|q_a|}}\,|\Omega_{-|q_a|}\rangle\right)+O(a'), \tag{15}$$

where $O(a')$ are terms that do not include a, and

$$\left|\Omega_{\pm|q_a|}\right\rangle = \sum_{b>a}^{N} \sqrt{P_{\Omega_{\pm a,b}}} \left|\Lambda_{\pm a,\mp b}\right\rangle. \tag{16}$$

If $P_{\pm|q_a|}$ is the probability of $\left|\Omega_{\pm|q_a|}\right\rangle$, and all $\left|\Lambda_{q_a,q_b}\right\rangle$ are orthonormal, then

$$\sum_{b>a}^{N} P_{\Omega_{\pm ab}} = 1. \tag{17}$$

Now, assuming that $P_{+|q_a|} = P_{-|q_a|}$ and $P_{\Omega_{+ab}} = P_{\Omega_{-ab}}$, (15) and (16) imply that

$$P_{\pm|q_a|} \cdot P_{\Omega_{\pm ab}} = P_{\pm a,\mp b} \tag{18}$$

corresponding to the probabilities of each $|\Lambda_{\pm a,\mp b,l}\rangle$ in *Axiom 2*, implying further that

$$P_{\pm|q_a|} = \frac{P_{\pm a,\mp b}}{P_{\Omega_{\pm ab}}} \tag{19}$$

The ratio of (19) is approximately the same for all $a \in A$, when $|A| \ll N$, assuming that

A1) All $P_{\pm a,\mp b}$ are constant in *Axiom 2,*

A2) All $P_{\Omega_{\pm ab}}$ are essentially constant for all a and for all $b > a$ in eq. (16);

thus, if $P_{\pm|q_a|}$ is the probability of $\left|\Omega_{\pm|q_a|}\right\rangle$, then *Axiom 1* implies that the average force of attraction on either $\psi_a^{(\pm|q_a|)}$ by an external charge $\vec{\boldsymbol{E}}_l$ is either

$$\vec{\boldsymbol{f}}_{al} = \pm P_{\pm|q_a|} \cdot |q_a| \vec{\boldsymbol{E}}_l \tag{20}$$

for all $a \in A$ where the effective EG-charge is the expression

$q_a^{eff} = \pm P_{\pm|q_a|} \cdot |q_a|$. (21)

Effective EG-charge for sets of WPs

Because certain types of elementary "particles" are made up of "attached" WPs as one sample, the average force on the "particle" by an external electric field is dependent on the sum of all the effective EG-charges of the WPs forming that sample. The dynamics of each WP is constrained by the others, unlike the case for "non-attached" WPs in the previous paragraph. In this case, the terms of $|EGE\rangle_N$ can be arranged by the polarity resulting from the sums of the possible effective EG-charges of the sample A, that is, net positive, negative or zero effective EG-charge. Mathematically speaking,

$$|EGE\rangle_N = \sum_{k^{(+)}}^{\gamma(+)} \left|\Omega_{\vec{\boldsymbol{q}}_{k^{(+)}}}^{(+)}\right\rangle + \sum_{k^{(-)}}^{\gamma(-)} \left|\Omega_{\vec{\boldsymbol{q}}_{k^{(-)}}}^{(-)}\right\rangle + \sum_{k^{(0)}}^{\gamma(0)} \left|\Omega_{\vec{\boldsymbol{q}}_{k^{(0)}}}^{(0)}\right\rangle + \sqrt{P_{\sim A}} \sum_{\mu>|A|}^{N-1} \sum_{\nu>\mu}^{N} \left(\sqrt{P_{\sim A_{+\mu,-\nu}}} |\Lambda_{+\mu,-\nu}\rangle + \sqrt{P_{\sim A_{-\mu,+\nu}}} |\Lambda_{-\mu,+\nu}\rangle \right), \tag{22}$$

such that

$$\left|\Omega_{\vec{\boldsymbol{q}}_{k^{(+)}}}^{(+)}\right\rangle = \sum_{a=1}^{|A|} B \sqrt{P_{q_a}} \left|\Omega_{q_{a_{k^{(+)}}}}\right\rangle \text{ for } \vec{\boldsymbol{q}}_{k^{(+)}} = \left(q_{1_{k^{(+)}}}, \dots, q_{|A|_{k^{(+)}}}\right)$$

where $\sum_{a=1}^{|A|} q_{a_{k^{(+)}}} > 0$,

$$|\Omega_{\vec{\boldsymbol{q}}_{k^{(-)}}}^{(-)}\rangle = \sum_{a=1}^{|A|} B \sqrt{P_{q_a}} |\Omega_{q_{a_{k^{(-)}}}}\rangle, \text{ for } \vec{\boldsymbol{q}}_{k^{(-)}} = (q_{k^{(-)}}, \dots, q_{|A|_{k^{(-)}}})$$

where $\sum_{a=1}^{|A|} q_{a_{k^{(-)}}} < 0$,

$|\Omega^{(0)}_{\vec{q}_{k^{(0)}}}\rangle = \sum_{a=1}^{|A|} B\sqrt{P_{q_a}}|\Omega_{q_{a_{k^{(0)}}}}\rangle$ for $\vec{\boldsymbol{q}}_{k^{(0)}} = (q_{1_{k^{(0)}}},\ldots,q_{|A|_{k^{(0)}}})$

where $\sum_{a=1}^{|A|} q_{a_{k^{(0)}}} = 0$, (23)

where each $\vec{\boldsymbol{q}}_{k^{(+)}}, \vec{\boldsymbol{q}}_{k^{(-)}}, \vec{\boldsymbol{q}}_{k^{(0)}}$ is unique; the state $|\Omega_{q_{a_{k^{(\pm)}}}}\rangle$ and $|\Omega_{q_{a_{k^{(0)}}}}\rangle$ are either $|\Omega_{\pm|q_a|}\rangle$, defined in eq. (16), associated with each $k^{(\pm)}$ and $k^{(0)}$. All P_{q_a} are essentially equal in (23), as implied by eq. (19) with assumptions A1) and A2) introduced in the previous paragraph. The last term in (22) corresponds to states that do not include any of the WPs from sample A. $\gamma_{(+)}, \gamma_{(-)}, \gamma_{(0)}$ refer to the respective total number of sum-combinations that can be made with additions of $B\sqrt{P_{q_a}}|\Omega_{q_a}\rangle$, with all the WPs of A, where each one of those sum-combinations corresponds to each $\vec{\boldsymbol{q}}_{k^{(+)}}, \vec{\boldsymbol{q}}_{k^{(-)}}, \vec{\boldsymbol{q}}_{k^{(0)}}$. The square of the coefficients, that is, $\left(B\sqrt{P_{q_a}}\right)^2$, corresponds the probability of any $|\Omega_{q_{a_{k^{(\pm)}}}}\rangle$ or $|\Omega_{q_{a_{k^{(0)}}}}\rangle$. In this way, eq. (22) is a special arrangement of the terms in eq. (15).

The first two summations in (23) can be arranged further so that the net intrinsic EG-charge $\sum_{a=1}^{|A|} q_{a_{k^{(\pm)}}}$ corresponds to a specific value. The number of terms in the third summation of (22), corresponding to zero net effective EG-charge, is the number of sum-combinations that can be made with half of the total number of WPs in the sample out of the total, each half corresponding to a specific polarity, that is,

$$\gamma_{(0)} = C^{|A|}_{|A|/2}, \tag{24}$$

if $|A|$ is an even number; thus, for the first two summations in eq. (22),

$$\gamma_{(\pm)} = \frac{1}{2}\left(2^{|A|} - C^{|A|}_{|A|/2}\right) \tag{25}$$

is the total number of terms where the net effective EG-charge is not zero, given that there is a total of $2^{|A|}$ ways to add $|A|$ of those EG-charges. Furthermore, the first two summations in (22) can be expanded so that each $\vec{\boldsymbol{q}}_{k^{(\pm)}}$ correspond to the same net effective EG-charge. Notice that

$$\frac{1}{2}(2^{|A|} - C^{|A|}_{|A|/2}) = \sum_{\eta=0}^{\frac{|A|}{2}-1} C^{|A|}_{|A|-\eta} \tag{26}$$

(which can be proven with mathematical induction and several instances of Pascal's combinatorial identity (BIGGS, 1990); thus, given (25) and (26), the first two summations in (22) become

$$\sum_{k^{(\pm)}}^{\gamma_{(\pm)}} \left|\Omega^{(\pm)}_{\vec{q}_{k^{(\pm)}}}\right\rangle = \sum_{\eta=0}^{\mathrm{H}} \sum_{\rho=1}^{\mathrm{P}(\eta)} \sum_{a=1}^{|A|} B\sqrt{P_{q_a}} \left|\Omega_{q_{a_{(\pm)(\eta,\rho)}}}\right\rangle \tag{27}$$

where

$$\mathrm{H} = \frac{|A|}{2} - 1 \tag{28}$$

and

$$\mathrm{P}(\eta) = C^{|A|}_{|A|-\eta} \tag{29}$$

for some bijective function $g(k^{(\pm)}) = (\pm)(\eta,\rho)$. In this manner, eq. (27) means that the net EG-charge

$$\sum_{a=1}^{|A|} q_{a_{k(\pm)}} = (\pm 1)\cdot(|A|-2\eta)|q_{a_{(\pm)(\eta,\rho)}}| \tag{30}$$

in (23), for each $\vec{\boldsymbol{q}}_{k^{(\pm)}}$: For every η, there are P(η) ways to add $|A|$ of the states $|\Omega_{q_{a_{k(\pm)}}}\rangle$ forming $|\Omega^{(\pm)}_{\vec{\boldsymbol{q}}_{k(\pm)}}\rangle$ with a subset of $\{k^{(\pm)}\}$, such that the net EG-charge of each $\vec{\boldsymbol{q}}_{k^{(\pm)}}$, corresponding to the elements of that subset, is the right-hand side of (30). There is a total of $|\mathrm{A}|/2-1$ different possible net EG-charge values that can be obtained by those additions for each of the two sample polarities. By establishing a one-to-one correspondence between each $k^{(\pm)}$ and the two variables $(\pm)(\eta,\rho)$, the net intrinsic EG-charge can be defined by (30) for $\{k^{(\pm)}\}$.

As implied by *Axiom 2*, eq. (22) must be normalized, which implies a relation between P_{q_a} and $P_{\sim A}$; such a relation is also true when combining (22) with (27). Plugging (27) into eq. (22), and defining

$$|{\sim}A\rangle = \sum_{\mu>|A|}^{N-1}\sum_{\nu>\mu}^{N}\left(\sqrt{P_{\sim A_{+\mu,-\nu}}}|\Lambda_{+\mu,-\nu}\rangle + \sqrt{P_{\sim A_{-\mu,+\nu}}}|\Lambda_{-\mu,+\nu}\rangle\right), \tag{31}$$

we can write

$$|EGE\rangle_N = \sum_{\eta=0}^{\mathrm{H}}\sum_{\rho=1}^{\mathrm{P}(\eta)}\sum_{a}^{|A|}\sqrt{\tfrac{1}{2^{|A|}}}\sqrt{P_{q_a}}\left|\Omega_{q_{a_{(+)(\eta,\rho)}}}\right\rangle$$

$$+\sum_{\eta=0}^{\mathrm{H}}\sum_{\rho=1}^{\mathrm{P}(\eta)}\sum_{a}^{|A|}\sqrt{\tfrac{1}{2^{|A|}}}\sqrt{P_{q_a}}\left|\Omega_{q_{a_{(-)(\eta,\rho)}}}\right\rangle + \sum_{k^{(0)}}^{\gamma_0}\sqrt{\tfrac{1}{2^{|A|}}}\sqrt{P_{q_a}}\left|\Omega^{(0)}_{\vec{q}_{k(0)}}\right\rangle + \sqrt{P}_{\sim A}|{\sim}A\rangle, \tag{32}$$

introducing $B=\sqrt{\frac{1}{2^{|A|}}}$ so that $\left(B\sqrt{P_{q_a}}\right)^2$ is the probability of any $|\Omega_{q_{a_{k(\pm)}}}\rangle$ or $|\Omega_{q_{a_{k(0)}}}\rangle$ in (32). In (31), notice that if $P_{\sim A}$ is the probability of $|{\sim}A\rangle$, then

$$\sum_{\mu>|A|}^{N-1}\sum_{\nu>\mu}^{N}\left(P_{\sim A_{+\mu,-\nu}} + P_{\sim A_{-\mu,+\nu}}\right) = 1 \tag{33}$$

given the orthonormality condition of all $|\Lambda_{q_a,q_b}\rangle$. Notice that by letting $\left(B\sqrt{P_{q_a}}\right)^2$ and $P_{\sim A}$ be the probabilities of the corresponding state-elements, implying (17) and (33), and combining eq. (23) with (22), inserting the given B and considering every P_{q_a} the same, the expression

$$\frac{P_{q_a}}{2^{|A|}}\left(\gamma_{(+)}+\gamma_{(-)}+\gamma_{(0)}\right)\cdot|A| + P_{\sim A} = 1 \tag{34}$$

follows if $|EGE\rangle_N$ is normalized. Eq. (24) and (25) imply that

$$\gamma_{(+)}+\gamma_{(-)}+\gamma_{(0)} = 2^{|A|}; \tag{35}$$

the latter combined with (34) imply further that

$$P_{\sim A} = 1 - P_{q_a}\cdot|A|. \tag{36}$$

Eq. (36) is a relation implied by a normalized $|EGE\rangle_N$, as required, in the form presented in (22). Consequently, (36) is also implied by eq. (32) if it is normalized.

Using several instances of *Axiom 1*, one can determine that the average net force on A by a homogeneous electric field $\overrightarrow{\boldsymbol{E}_l}$, for a specific η' in (32), is

$$\vec{\boldsymbol{f}}_{Al} = P^{(\pm)}_{A_{(\eta')}}\sum_{a}^{|A|} q_a\overrightarrow{\boldsymbol{E}_l}, \tag{37}$$

where

$$P^{(\pm)}_{A_{(\eta')}} = \frac{P_{q_a}}{2^{|A|}} \cdot \mathrm{P}(\eta') \qquad (38)$$

given the meaning of $\left(B\sqrt{P_{q_a}}\right)^2$ and that there are $\mathrm{P}(\eta')$ of those. Given (30), eq. (37) and (38) imply that the effective EG-charge is

$$|q^{eff}_{A_{(\eta')}}| = \frac{P_{q_a}}{2^{|A|}} \cdot \mathrm{P}(\eta') \cdot (|A| - 2\eta')|q_a|. \qquad (39)$$

Thus, the magnitude of the average force on A by the external electric field, for a specific η', is

$$|\vec{\boldsymbol{f}}_{Al}| = \frac{P_{q_a}}{2^{|A|}} \cdot \mathrm{P}(\eta') \cdot (|A| - 2\eta')|q_a| \cdot |\vec{\boldsymbol{E}}_l|. \qquad (40)$$

Variations in the magnitude of gravitational force

As implied in *Axiom 3*, the GM of a WP forming an EGE can increase (or decrease). Notice that the probability $P_{\pm a,\mp b}$ depends on the number of all $|\Lambda_{\pm a,\mp b}\rangle$ in $|EGE\rangle_N$, as shown in *Axiom 2*, given that the state-elements form a complete set. Decreasing (or increasing) their number, *ceteris paribus*, implies an increment (or diminishment) in $P_{\pm a,\mp b}$ which implies, by *Axiom 1*, that the average magnitude of the force of attraction between those two WPs is greater. Such an increment (or diminishment) in the average magnitude of that force corresponds to the increment (or diminishment) in the GM in *Axiom 3*.

Furthermore, the GM of another WP c can change as well if $P_{\pm a,\mp b}$ changes, *ceteris paribus*, for any pair of WPs a and b such that $c \neq a$ & $c \neq b$, given that the probability $P_{\pm c,\mp c'}$ for that WP and another c', such that $c' \neq a$ & $c' \neq b$, would change as the result of the completeness conditions of all $|\Lambda_{\pm a,\mp b}\rangle$. Such a change in $P_{\pm c,\mp c'}$ is the case when instead of two OPPS, $|\Lambda_{+a,-b}\rangle$ or $|\Lambda_{-a,+b}\rangle$, for the two WPs a and b, an interaction defines one state or the other. The analysis can be generalized to macroscopic objects, regarding each as subsets of the total number of WPs. In this manner, such a detection of the polarity of the EG-charges of some WP, *ceteris paribus*, implies an increment in the GM of all other objects as well.

In particular, notice that detection of net effective EG-charge of a "particle", corresponding to η', reduces eq. (32) to

$$|EGE\rangle^{(\pm R)} = C^{(\pm)}\left(B \cdot \sqrt{P_{q_a}} \sum_{\rho=1}^{\mathrm{P}(\eta')} \sum_{a}^{|A|} \left|\Omega_{q_{a_{(\pm)(\eta',\rho)}}}\right\rangle + \sqrt{P}_{\sim A}|{\sim}A\rangle\right) \qquad (41)$$

where

$$C^{(\pm)} = \sqrt{\frac{1}{B^2 \cdot P_{q_a} \cdot \mathrm{P}(\eta') \cdot |A| + P_{\sim A}}}, \qquad (42)$$

given the orthonormality condition of all $|\Lambda_{q_a,q_b}\rangle$, eq. (17) and (33), and that the reduced state (41) itself is normalized; $(\pm)$ indicates the polarity of the effective EG-charge detected. To calculate the average force on the WP $a \in A$ by $b \notin A$, in state (41), *Axiom 1* can be applied, where the probability of each $|\Lambda_{\pm a,\mp b}\rangle$, forming part of $|\Omega_{q_{a_{(\pm)(\eta',\rho)}}}\rangle$, is

$$P^{(\pm)}_{\pm a,\mp b} = \left(C^{(\pm)}\right)^2 B^2 \cdot P_{q_a} \cdot \mathrm{P}(\eta') \cdot P_{\Omega_{ab}} \qquad (43)$$

given eq. (41), (42), and (16), where $P_{\Omega_{ab}} = P_{\Omega_{+ab}}$ or $P_{\Omega_{-ab}}$, corresponding to $P_{q_a} = P_{+|q_a|}$ or $P_{-|q_a|}$. In this way, expression (43), and *axiom 1,* imply that the average force on either $\pm q_a$ by $\mp q_b$, with either $(\pm)$ representing the effective EG-charge polarity of the set A, is

$$\vec{\boldsymbol{f}}^{(\pm)}_{\pm a,\mp b} = \left(C^{(\pm)}\right)^2 B^2 \cdot P_{q_a} \cdot \mathrm{P}(\eta') \cdot P_{\Omega_{ab}} \cdot \frac{K q_a q_b}{|\vec{r}_{ab}|^2}\, \hat{\boldsymbol{r}}_{ab}. \qquad (44)$$

Using (43) also with *Axiom* 3 because the right side of such an expression is the probability that a and b have charges q_a and q_b as shown in (44), entails that

$$m_a^R(\eta') = C^{(\pm)} B \sqrt{P_{q_a} \cdot \mathrm{P}(\eta') \cdot P_{\Omega_{ab}}} |q_a| \sqrt{\frac{K}{G}}, \tag{45}$$

where $P_{q_a} \cdot P_{\Omega_{ab}} = P_{+a,-b}$ or $P_{-a,+b}$, as indicated in (18); one of those two probabilities vanish when detecting $(\pm)$ effective EG-charge. Combining (45) with the relation between mass and charge in *Axiom 3* corresponding to an EGE that is not reduced, assuming $P_{+a,-b} = P_{-a,+b}$ and using (18), implies

$$m_a^R(\eta') = C^{(\pm)} B \sqrt{\frac{\mathrm{P}(\eta')}{2}} \cdot m_a \tag{46}$$

On the other hand, notice that detection of effective EG-charge with WPs of set A implies that any WP $\mu \notin A$ and $\upsilon \notin A$, in eq. (41), also changes the probability $P_{\pm\mu,\mp\upsilon}$ of all the corresponding $|\Lambda_{\mu,\upsilon}\rangle$ because $C^{(\pm)}$ is applicable to all those state elements as well. Not only the detection of effective EG-charge in a "particle" changes its GM, but also changes the GM of WPs $\mu, \upsilon \notin A$.

A theoretical test by exposure to a homogeneous electric field

Figure 1 depicts a thought experiment to test the model. The analysis is analogous to the splitting of spin-1/2 WPs passing through a magnetic field, to make an impulsive measurement (BOHM, 1989), except that in the present case it is a homogeneous electric field with hypothetical charges. Keeping the Ehrenfest theorem in mind (FRIESECKE and KOPPEN, 2009), we treat the average of specific quantities as their classical counter parts. All of the neutron physical quantities will refer to averages unless stated otherwise. In this way, as shown in Fig. 1, we may say that the neutrons are exposed to an electric field $\vec{\boldsymbol{\epsilon}}$, along the x-direction, for a time τ, providing those neutrons with momentum $\pm p_{I_x}$, where their displacement magnitudes depend on their effective EG-charges. After exposure, the neutrons are allowed to spread freely for an additional time Δt. Eq. (40) implies

$$p_{I_x} = |q_{A(\eta')}^{eff}| \cdot |\vec{\boldsymbol{\epsilon}}| \cdot \tau, \tag{47}$$

for some η', assuming that the uncertainty of τ is negligible; $q_{A(\eta')}^{eff}$ is defined by (39). The displacement is

$$\vec{\boldsymbol{x}} = \pm \frac{p_{I_x}}{M_I} \Delta t \hat{\boldsymbol{x}}\,, \tag{48}$$

where M_I the inertial mass of each neutron. Combining the two previous expression imply

$$\vec{\boldsymbol{x}} = \pm \frac{|q_{A(\eta')}^{eff}|}{M_I} \cdot |\vec{\epsilon}| \cdot \tau \cdot \Delta t \hat{\boldsymbol{x}}. \tag{49}$$

Now, considering the effective EG-charge is eq. (39), combining it with *Axiom 3,* setting $P_{ab} = P_{+a,-b} = P_{-a,+b}$ to express each $|q_a|$ in terms of m_a (i.e. the GM of a WP before interacting with the electric field), the displacement becomes

$$\vec{\boldsymbol{x}} = \pm \frac{P_{q_a}}{\sqrt{2P_{ab}}} \cdot \frac{1}{2^{|A|}} \cdot \mathrm{P}(\eta') \cdot (|A| - 2\eta') \cdot \frac{1}{|A|} \cdot \sqrt{\frac{G}{K}} \cdot |\vec{\boldsymbol{\epsilon}}| \cdot \tau \cdot \Delta t\, \hat{\boldsymbol{x}} \tag{50}$$

given that the neutron's inertial mass

$$M_I = |A| \cdot m_I, \tag{51}$$

where m_I is the inertial mass of one WP within the neutron, and setting

$$m_I = m_a. \tag{52}$$

Furthermore, to make a calculation of $\vec{\boldsymbol{x}}$, *we hypothesize that the rest mass of one neutrino* (ν) *is related to* $|q_a|$ *in Axiom 3*; thus, for the neutron,

$$|A_>| = 1.172 \times 10^9 \tag{53}$$

is a lower bound for $|A|$ given that 1.67×10^{-27} kg is the mass of the neutron and 1.424×10^{-36} kg (i.e. $0.8\ \mathrm{eV/c^{-2}}$) is an upper bound for the neutrino's mass (AKER *et al.*, 2022); (53) is implied by their ratio. The effective EG-charge for the neutrons was calculated for

$$\eta_{max} = \frac{|A_>|}{2} - 1, \tag{54}$$

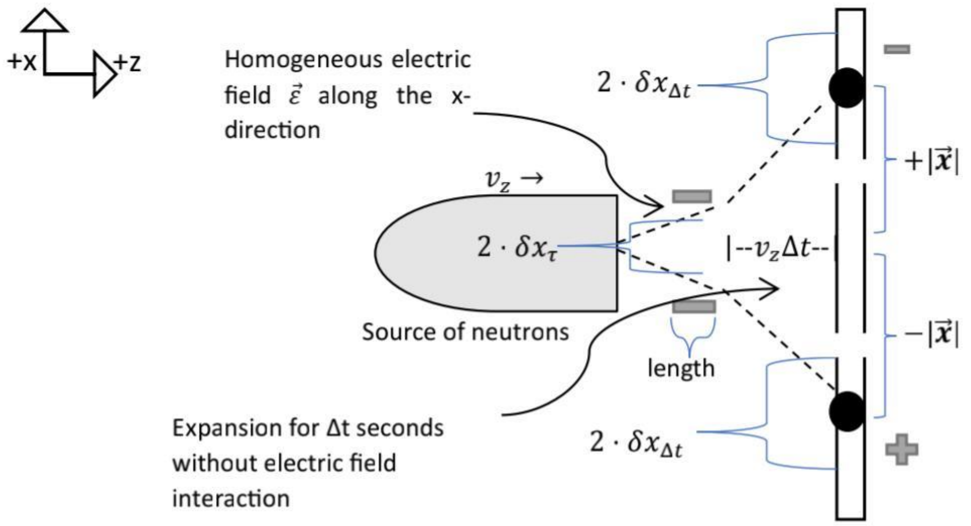

Figure 1. Top view of the thought experiment to test the relation between gravitational mass and electric charge. Neutrons move through a strong electric field that is perpendicular to their velocities. Those neutrons displace beyond their position uncertainties. (The picture is not to scale).

the maximum possible for η as stated in (28), that also corresponds to the maximum $P(\eta)$ possible, implied by (29), which is as well the maximum displacement implied by (50). We neglect perturbations that might result from the charge distribution within the neutron(ALEXANDER *et al.*, 2021; ATAC *et al.*, 2021), that would alter eq. (50), e.g., when those neutrons move out of the homogeneous field. Nevertheless, the thought experiment is theoretically possible.

One necessary condition is that the displacement magnitude $|\vec{\boldsymbol{x}}|$, after Δt, has to be much greater than the position uncertainty $\delta x_{\Delta t}$ that results from the expansion of the initial uncertainty δx_τ immediately after the exposure, that is,

$$|\vec{\boldsymbol{x}}| \gg \delta x_{\Delta t}, \tag{55}$$

where

$$\delta x_{\Delta t} - \delta x_\tau \approx \delta p_x \cdot \frac{\Delta t}{M_I}, \tag{56}$$

setting

$$\delta x_{\Delta t} \gg \delta x_{\tau} \tag{57}$$

so that δx_{τ} can be neglected in (56). From (55),(56), (57), using eq. (50), and requiring that

$$M_I v_z \gg \delta p_x \text{ and } M_I v_z \gg \delta p_z \tag{58}$$

where v_z is the speed of the neutrons in the z-direction and the right-hand sides are the quantum momentum uncertainties along both directions, the inequality

$$\frac{|\vec{x}|}{\Delta t} \geq v_z \tag{59}$$

necessarily implies $\delta x_{\Delta t} \ll v_z \cdot \Delta t \leq |\vec{x}|$. In this manner, detecting the effective EG-charge of neutrons in this theoretical experiment requires maximizing the product of $|\vec{\epsilon}|$ and τ in (50), while minimizing v_z sufficiently so that (59) is satisfied. Inequality (59) guarantees (55), to be able to make a detection, if (57) and (58) are true.

Notice that (58) implies that the z-uncertainty is $\delta z \gg \hbar/(M_I v_z)$, and that the one for τ is $\delta\tau \gg \hbar/(M_I v_z^2/2)$. To make detections of effective EG-charge with the setup shown in fig. 1, the length and time of exposure have to be much greater than those uncertainties, whose values have to be much greater than the lower bounds implied by those two relations.

On the other hand, the electric field does not have to cause significant change to the neutrons' wave functions during the exposure time τ, but only provides the momentum necessary to displace them appreciably after leaving the electric field region. That means that the electric field is strong enough to provide momentum in a short time but the displacement in the region of the electric field is much smaller than $|\vec{x}|$. Mathematically speaking, $\frac{p_{I_x}}{M_I}\Delta t \gg \frac{p_{I_x}}{M_I}\tau$ if we regard p_{I_x} as the maximum possible momentum magnitude along the x-direction. It follows that another condition to make a detection of effective EG-charge is

$$\Delta t \gg \tau. \tag{60}$$

Notice that (60) implies that

$$\frac{\delta p_x}{M_I}\Delta t \gg \frac{\delta p_x}{M_I}\tau \tag{61}$$

which implies further that

$$\delta x_{\Delta t} - \delta x_{\tau} \gg \delta x_{\tau} - \delta x_0, \tag{62}$$

using (56) and letting $\delta x_{\tau} - \delta x_0 = \frac{\delta p_x}{M_I}\tau$, where δx_0 is the uncertainty right before the exposure. Consequently, if (60) is true, letting $\delta x_{\tau} \gg \delta x_0$ so that $\delta x_{\tau} \approx \frac{\delta p_x}{M_I}\tau$, then (57) follows.

We created a table of values, corresponding to ultra-cold speeds (DÖGE *et al.*, 2020), making sure that the net time $\tau + \Delta t$ was much smaller than their mean lifetime (GONZALES *et al.*, 2021), generating "random" variations of the parameters in eq. (50) in an Excel spreadsheet; then, the left side of inequality (59) was calculated to distinguish those that exceeded the right of the relation. One of the entries was hand-picked as one of many "optimal" parameter combinations to compare to those "randomly" generated. The variations in the electric field ranged from 10^{23} N/C to 10^{27} N/C (each step is increased by a factor of 10); the times of exposure ranged from 0.5 s to 2.5 s (in steps of 0.5 s); the time of free expansion ranged from 5 s to 10 s (in steps of 1 s); the range of speeds was from 5 m/s to 20 m/s (in steps of 5 m/s). The aim of the hand-picked set of optimal parameter values was to present a set where those for the electric field were as small as possible, the displacement did not exceed 200 m (no theoretical significance for the number; just practical considerations), with an exposure length less than 5 m (just for convenience), and making sure that the exposure lengths and times were consistent with the quantum uncertainties implied by (58).

RESULTS AND DISCUSSION

Using previous expressions, specific values for the thought experiment presented in fig. 1 were obtained. To calculate $|\vec{\boldsymbol{x}}|$ using (50),

$$\frac{P_{q_a}}{\sqrt{2P_{ab}}} \tag{63}$$

was determined first in the limit that N is large; the rest was calculated with

$$\mathrm{P}\left(\frac{|A_>|}{2}-1\right)=C^{|A_>|}_{|A_>|-\left(\frac{|A_>|}{2}-1\right)}. \tag{64}$$

From the completeness statement in *Axiom 2*, and assumption A1), such that $P_{ab}=P_{+a,-b}=P_{-a,+b}$, follows that

$$P_{ab}=\frac{1}{N(N-1)}. \tag{65}$$

Notice that

$$P_{q_a}\approx\frac{1}{N}\cdot\frac{N-a}{N-1} \tag{66}$$

is the probability of the corresponding states if

$$P_{\Omega_{\mathrm{ab}}}\approx\frac{1}{N-a}, \tag{67}$$

given eq. (19) and (65); eq. (67) is the case given (17) and given assumption A2). Inserting eq. (65) and (66) into (63), imply

$$\frac{P_{q_a}}{\sqrt{2P_{ab}}}\approx\frac{1}{N}\cdot\frac{N-a}{N-1}\cdot\frac{\sqrt{N(N-1)}}{\sqrt{2}}\ ; \tag{68}$$

however, given that $|A|\ll N$ and that $a\in A$,

$$\text{as } N\to\infty\ ,\ \frac{P_{q_a}}{\sqrt{2P_{ab}}}\to\frac{1}{\sqrt{2}}, \tag{69}$$

implying that eq. (50) becomes

$$\vec{\boldsymbol{x}}=\pm\left(\frac{1}{\sqrt{2}}\right)\cdot\frac{1}{2^{1.172\times10^{9}}}\cdot\mathrm{P}\left(\frac{1.172\times10^{9}}{2}-1\right)\cdot 2\cdot\frac{1}{1.172\times10^{9}}\cdot\sqrt{\frac{G}{K}}\cdot|\vec{\boldsymbol{\epsilon}}|\cdot\tau\cdot\Delta t\,\hat{\boldsymbol{x}} \tag{70}$$

given (25), (53), (64) and (69). Thus, the $\vec{\boldsymbol{x}}$ does not depend explicitly on N.

An upper bound for the GM of a neutron, $M^{R}_{n^{0}}$, after the interaction, was calculated using

$$M_{n^o}=|A_>|\cdot m_a \text{ and } M^{R}_{n^o}=|A_>|\cdot m^{R}_{a}, \tag{71}$$

where m_a the upper bound for the rest mass of the neutrino, and m^{R}_{a} is the reduced mass of that neutrino corresponding to (46) after the detection. (36), (53), (64), and (66) imply that $C^{(\pm)}\approx 1$ in (42) for large N; thus, together with (53) and (64) in eq. (46) imply

$$M^{R}_{n^o}(\eta_{max})\approx 3.413\times10^{-3}M_{n^o}, \tag{72}$$

indicating a considerable reduction in the GM of the neutrons after the detection of their effective EG-charges.

An upper bound for the effective EG-charge of the neutron is 4.044×10^{-51} C; it was calculated using (39), the relation in *Axiom 3* with $P_{+a,-b} = P_{-a,+b}$, eq. (53), (54), (64), (69), and the upper bound for the rest mass of the neutrino (i.e. 1.424×10^{-36} kg).

Table 1. Calculations of the hypothetical displacements of neutrons (n^0) by exposure to electric fields.

	$\lvert\vec{\epsilon}\rvert$ $(\mathbf{N/C})$	$\boldsymbol{\tau}$ $(\mathbf{s})$	$\boldsymbol{v_z}$ $(\mathbf{m/s})$	$\boldsymbol{\Delta t}$ $(\mathbf{s})$	$\lvert\vec{x}\rvert$ $(\mathbf{m})$	$\frac{\lvert\vec{x}\rvert}{\Delta t}$ $(\mathbf{m/s})$	$\frac{\lvert\vec{x}\rvert}{\Delta t} > v_z$	**Exposure length (m)**
N.A.	1×10^{25}	0.5	5	10	121.12	12.11	**TRUE**	2.5
1)	1×10^{23}	0.5	15	10	1.21	0.12	**FALSE**	7.5
2)	1×10^{25}	0.5	15	8	96.90	12.11	**FALSE**	7.5
3)	1×10^{26}	2	15	9	4360.33	484.48	**TRUE**	30
4)	1×10^{27}	1.5	10	5	18168.04	3633.61	**TRUE**	15
5)	1×10^{27}	2.5	10	7	42392.08	6056.01	**TRUE**	25
6)	1×10^{24}	2.5	15	9	54.50	6.06	**FALSE**	37.5
7)	1×10^{25}	1.5	20	5	181.68	36.34	**TRUE**	30
8)	1×10^{24}	2	20	9	43.60	4.84	**FALSE**	40
9)	1×10^{26}	1	10	7	1695.68	242.24	**TRUE**	10
10)	1×10^{24}	2.5	15	8	48.45	6.06	**FALSE**	37.5

With the exception of the first row, Table 1 presents "random" values for ultra-cold and nearly ultra-cold neutrons, and whether or not they satisfy (59), setting the "factor"

$$\left(\frac{1}{\sqrt{2}}\right) \cdot \frac{1}{2^{1.172\times10^{9}}} \cdot \mathrm{P}\left(\frac{1.172\times10^{9}}{2} - 1\right) \cdot 2 \cdot \frac{1}{1.172\times10^{9}} = 2.812 \times 10^{-14} \tag{73}$$

corresponding to (64), as well as the corresponding displacements $|\vec{x}|$, using eq. (70), and the length of the region of electric field exposure. The first four unit-columns, from the left, are the four input parameters. With the exception of the first row, those parameters were varied "randomly" in all the rows. Given that the "factor" is defined by (73), (the combinatorial formula was calculated using "Scientific Calculator plus 991" available at Google Play) the x-displacement defined by (50) was calculated for large N (numbers were rounded); then, the left side of inequality (59) was recorded in the next column (numbers were also rounded). The inequality was verified when "TRUE" was the outcome in our Excel spreadsheet. The length of the exposure can be implied from the time of exposure and speed considering that the uncertainties in those two parameters are not significant. Now, one may observe that not every combination of electric field $|\vec{\epsilon}|$, time of exposure τ, and speed v_z satisfies inequality (59). Also, notice that the addition of the time of exposure τ with the free time of expansion Δt for all entries are much less that the mean lifetime of an isolated neutron (that is, less than 887.7 seconds). The first row represents one of many optimal designs, within the range of variations, that was hand-picked for comparison with those "randomly" generated: the magnitude of the electric field is not the maximum value possible in the range, with neutrons moving with the slowest speed possible in the range. In this optimal entry, the expansion time is 20 times the time of exposure. Both, the displacement and length of the exposure were smaller than 200 m and 5 m respectively (number picked for practical considerations) in this hand-picked entry. On the other hand, Table 1 presents only lower bounds for the electric fields that result in the displacements shown, given that (53) is only a lower bound used to calculate the "factor" with (73) based on the upper bound for the neutrino rest mass. The field values needed for the thought experiment are much above the Schwinger limit (BUCHANAN, 2006).

The lengths and times of exposure, for all entries in Table 1, can be far greater than their possible corresponding uncertainties $\delta z \gg \hbar/(M_I v_z)$ and $\delta\tau \gg \hbar/(M_I v_z^2/2)$ that are implied by requiring (58). Thus, it is possible in theory to make detections of effective EG-charge in the thought experiment, given the lengths and times introduced, and given an electric field that is sufficiently strong.

One significant aspect of our model is the testable macroscopic entanglement. The axioms introduced imply the attraction of ordinary macroscopic objects, with hypothesized quantum entanglements, that have remained essentially coherent for the time that galaxies have existed. Empirical confirmation of the results shown in Table 1, or similar detectable interaction of GM with an electric fields, corresponding to a parameter even greater than (53), would verify such a macroscopic entanglement and the conditions for its decoherence. Notice that in the experiment proposed, the environment is part of the macroscopic entanglement. Even every microstate of every piece of equipment of the thought experiment depicted in fig. 1, in principle, cannot be separated from the EGE. Yet, the "randomness" in the macroscopic events, e.g., the direction of the homogeneous field, are not correlated in principle with the entanglement under consideration. In this manner, confirmation of the EGE could lead to new evidence-based causal interpretations of quantum mechanics, involving a physical property of classical mechanical objects, without violating the measurement independence postulate (CHAVES *et al*., 2001).

Furthermore, the EGE introduced could also be created in the lab, somehow, with ordinary electric charges to simulate gravity, and test whether such a field corresponds to the properties of an actual gravitational field. Rather than testing ordinary GM to verify whether or not it forms part of an EGE, ordinary electric charges could be entangled to create a gravity-like field, for simulations, as some have realized in laboratory conditions with quantum systems (NEZAMI *et al*., 2023; VAN DER MEER *et al*., 2023). To create an EGE, a minimum of two entangled charges would be sufficient for such an experiment. In this manner, finding ways to create an EGE in the lab is another research path with the model introduced that could have practical applications.

CONCLUSION

With a homogeneous electric field above the Schwinger limit, and exposing neutrons moving at ultra-cold speeds, it is possible to make detections of the maximum possible effective EG-charge if gravity is a macroscopic EGE, assuming the axioms introduced. Mathematically speaking, those axioms do simulate Newtonian gravitation with electric charges. Given our estimate for the upper bound of the smallest GM possible, an electric field of approximately 1×10^{25} N/C is a reasonable lower bound for an experimental test.

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