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ON SEPARATION OF EXCHANGE TERMS FOR FOUR-POTENTIAL ACOUSTIC SH-WAVE CASE WITH DEPENDENCE ON GRAVITATIONAL PARAMETERS

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Abstract

One of major achievements in modern physics is investigations of complex systems consisting of mechanical, electrical, magnetic, gravitational, and cogravitational subsystems. The recently developed theory provides the coupling coefficient among these subsystems. It is called the coefficient of the electromagnetogravitocogravitomechanical coupling (CEMGCMC) K_{emgc}^2. This coupling coefficient is one of the very important characteristics of a studied solid material and all the four-potential shear-horizontal acoustic waves depend on this coefficient. This report analytically studies the CEMGCMC concerning separation of several exchange terms. It is also discussed the possible propagation speeds such as the well-known speed of light in a vacuum for the purely electromagnetic wave and purely gravitational wave. However, some exchange mechanisms between the electromagnetic and gravitational subsystems can result in the existence of the other exchange speeds, with which generated signals representing neither purely electromagnetic nor purely gravitational waves can propagate in a vacuum with speeds several orders larger than the speed of light. The evaluated maximum value of this speed must be below ~ 10^{27} m/s representing the speed with which a signal can cross for one second from one boundary of our Universe to the opposite. This can mean that such signals once generated inside of our Universe can instantly reach any other point in the Universe. It is also hoped that this theoretical work will contribute to the development of such new research discipline as the gravitational engineering.

Keywords: Continuous media; Gravitational effects; Magnetoelectric effect; Four-potential coupling problem; Exchange terms.

1 Introduction

Investigations of acoustic wave propagation coupled with the electrical, magnetic, gravitational, and cogravitational potentials (i.e. four-potential acoustic wave) represent a complicated problem. For this problem there are a lot of material parameters that can contribute in the wave motions. However, it is a pleasure to deal with a single material parameter that can significantly simplify the studying subject. This single material parameter is called the coefficient of the electromagnetogravitocogravitomechanical coupling (CEMGCMC) K^2_{emgc}. This coupling coefficient represents a very important characteristic of a studied solid material. It depends on all the material parameters, but the mass density ρ. The CEMGCMC is an indicator of coupling among the mechanical, electrical, magnetic, gravitational, and cogravitational subsystems. For instance, the four-potential shear-horizontal (SH) surface [1], interfacial [2], and plate [3] acoustic waves can depend on this material parameter.

The examination of propagation of four-potential acoustic waves has the following peculiarity: the speed of any acoustic wave in a solid is five orders smaller than the speed of the electromagnetic wave in the solid. Also, the speed of the electromagnetic wave in any solid must be (slightly) smaller than the speed of light in a vacuum. Therefore, the quasi-static approximation can be applied for this case. In 2016, a large research group consisting of more than one thousand of collaborators [4] has experimentally demonstrated that the speeds of the gravitational and electromagnetic waves in a vacuum are equal. The gravitational wave existence was predicted by Einstein [5] in 1916. Heaviside [6] in 1893 has first focused an attention of researchers on an analogy between the electromagnetic and gravitational phenomena. Therefore, the famous book by Jefimenko [7] published in 2006 has further developed Newton's theory of gravitation assuming that Newton's gravitation coexists with cogravitation. The coupling between the gravitation and cogravitation can result in the gravitational wave propagation in a vacuum. In 2016, Füzfa [8] has discussed some ideas of evaluation of interactions between the electrical or magnetic subsystem with the gravitational or cogravitational subsystem. This can allow researchers in the future to control some changes in the gravitational or cogravitational subsystem by created changes in the electrical or magnetic subsystem, i.e. some artificial gravitational fields can be created in a laboratory at the Earth conditions. It is necessary to state here that any type of energy and changes in energy actually produce gravitation in the same way. And any type of wave motion carries some energy over the way from the wave generator to the wave detector. It is obvious that the CEMGCMC combines contributions from each of the mechanical, electrical, magnetic, gravitational, and cogravitational subsystems. These contributions for different solid materials can be different. And it is expected that these contributions can show even a dramatic difference for some suitable solids.

With the CEMGCMC, the theoretical investigations of this work obtain and discuss several exchange terms. These terms couple the possible exchange processes that can exist among the subsystems. The following section provides the analytical expressions that can be useful for more complete understanding of some aspects of the studied complex system consisting of the mechanical, electrical, magnetic, gravitational, and cogravitational subsystems. The following section also touches some questions concerning different wave motions in both solids and a vacuum for discussion. The third section mathematically obtains the exchange terms and some problems are discussed in the last section.

2 The material parameters

Consider a solid material, for which the wave motion accumulates nonzero contributions from each of the mechanical, electrical, magnetic, gravitational, and cogravitational subsystems. The reader must be familiar with the cogravitational subsystem that can coexist with gravitational subsystem. This is an analogy to the coexistence of electrical and magnetic subsystems, for instance, in order to form an electromagnetic wave. This analogy was first stated by Heaviside [6]. In this direction, Newton's theory of gravitation created in 1687 was then developed by many researchers, for instance, by Jefimenko [7]. In

2016, both the gravitation and the cogravitation were taken into account in developed theory concerning the acoustic wave propagation in anisotropic solids [1]. With the transversely isotropic crystal of symmetry class 6 *mm*, the velocities of the anti-plane polarized bulk and surface acoustic waves can be respectively calculated with the following formulae [1]:

$$V_{temgc} = \sqrt{C\left(1 + K_{emgc}^2\right)/\rho} \tag{1}$$

$$V_{newSAW} = V_{temgc}\left[1 - \left(\frac{K_{emgc}^2}{1+K_{emgc}^2}\right)^2\right]^{1/2} \tag{2}$$

In definition (1), the velocity V_{temgc} is called the four-potential shear-horizontal bulk acoustic wave (4P-SH-BAW) because the acoustic wave propagation is coupled with the electrical, magnetic, gravitational, and cogravitational potentials. In definition (2), the velocity V_{newSAW} is analogically called the four-potential shear-horizontal surface acoustic wave (4P-SH-SAW) that was recently discovered in paper [1]. In general, an SH-SAW can be treated as an instability of the SH-BAW. In definition (1), the material parameters ρ and C respectively stand for the mass density and the elastic stiffness constant listed in table 1. It is clear seen in expressions (1) and (2) that both the bulk and surface acoustic waves depend on the nondimensional parameter K_{emgc}^2 called the coefficient of the electromagnetogravitocogravitomechanical coupling (CEMGCMC).

The coefficient K_{emgc}^2 is the very important coupling mechanism and represents a very complicated material parameter depending on all the material parameters listed in table 1, but the mass density ρ. Therefore, this coefficient can be calculated with the following formulae ([1],[2],[3],[9]):

$$K_{emgc}^2 = \frac{B_1}{CB_2} \tag{3}$$

where

$$B_1 = e^2(\mu\gamma\eta + 2\beta\lambda\vartheta - \lambda^2\gamma - \beta^2\eta - \vartheta^2\mu) + h^2(\varepsilon\gamma\eta + 2\zeta\xi\vartheta - \vartheta^2\varepsilon - \zeta^2\eta - \xi^2\gamma) + g^2(\varepsilon\mu\eta + 2\alpha\xi\lambda - \lambda^2\varepsilon - \alpha^2\eta - \xi^2\mu) + f^2(\varepsilon\mu\gamma + 2\alpha\beta\zeta - \beta^2\varepsilon -$$

$$\alpha^2\gamma - \zeta^2\mu) + 2eh(\zeta\beta\eta + \xi\gamma\lambda + \vartheta^2\alpha - \alpha\gamma\eta - \zeta\lambda\vartheta - \xi\beta\vartheta) + 2eg(\alpha\beta\eta + \xi\vartheta\mu + \lambda^2\zeta - \alpha\lambda\vartheta - \zeta\mu\eta - \xi\beta\lambda) + 2ef(\alpha\gamma\lambda + \zeta\vartheta\mu + \beta^2\xi - \alpha\beta\vartheta - \zeta\beta\lambda - \xi\mu\gamma) + 2hg(\varepsilon\lambda\vartheta + \zeta\alpha\eta + \xi^2\beta - \alpha\xi\vartheta - \zeta\lambda\xi - \varepsilon\eta\beta) + 2hf(\varepsilon\beta\vartheta + \xi\alpha\gamma + \zeta^2\lambda - \alpha\zeta\vartheta - \zeta\xi\beta - \varepsilon\lambda\gamma) + 2gf(\varepsilon\beta\lambda + \xi\mu\zeta + \alpha^2\vartheta - \alpha\zeta\lambda - \alpha\beta\xi - \varepsilon\mu\vartheta) \quad (4)$$

$$B_2 = (\varepsilon\mu - \alpha^2)(\gamma\eta - \vartheta^2) + (\beta\xi - \lambda\zeta)^2 - (\xi^2\mu\gamma + \beta^2\varepsilon\eta + \lambda^2\varepsilon\gamma + \zeta^2\mu\eta) + +2(\gamma\alpha\xi\lambda + \eta\alpha\beta\zeta + \varepsilon\beta\lambda\vartheta + \mu\zeta\xi\vartheta - \alpha\zeta\lambda\vartheta - \alpha\beta\xi\vartheta) \quad (5)$$

It is necessary here to mention useful physical dimensions of some combinations of the material parameters. With table 1, one can find the following equalities:

$$[\rho/C] = [\varepsilon\mu] = [\gamma\eta] = [\alpha^2] = [\vartheta^2] = [\alpha\vartheta] = [\xi\beta] = [\zeta\lambda] = [s^2/m^2] \quad (6)$$

Indeed, the speed of the electromagnetic wave propagating in a solid can be calculated with the following well-known formula:

$$V_{EM} = \frac{1}{\sqrt{\varepsilon\mu}} \quad (7)$$

Analogically, the propagation speed of the gravitocogravitic wave (gravitational wave) in a solid can be evaluated with the following expression:

$$V_{GC} = \frac{1}{\sqrt{\gamma\eta}} \quad (8)$$

For a solid possessing the magnetoelectric (ME) effect, some exchange between the electrical and magnetic subsystems can be characterized by the electromagnetic constant α. Therefore, the following exchange speed between the subsystems can be calculated:

$$V_\alpha = \frac{1}{\alpha} \quad (9)$$

It is necessary to state here that the exchange speed (9) should be faster than the speed of the electromagnetic wave (7), i.e. $V_\alpha > V_{EM}$ because $\alpha^2 < \varepsilon\mu$ ([10],[11]) should occur. In general, for any ME solid, one can find that $V_\alpha >>$

V_{EM} due to $\alpha^2 << \varepsilon\mu$. The evaluation of these material parameters in table 1 demonstrates that these inequalities occur.

Table 1: The material parameters, their estimated values and fundamental physical dimensions. The propagation direction of the acoustic 4P-SH-wave is perpendicular to the 6-forld symmetry axis of the transversely isotropic material of symmetry class 6 *mm*.

Material parameter	Symbol and [dimension]	Estimated values
Mass density	ρ [kg/m^3]	10^3
Elastic stiffness constant	$C = C_{44} = C_{66}$ [kg/(m×s^2)]	10^9 to 10^{11}
Piezoelectric constant	$e = e_{16} = e_{34}$ [kg$^{1/2}$/m$^{3/2}$]	0.1 to 10
Piezomagnetic coefficient	$h = h_{16} = h_{34}$ [kg$^{1/2}$/(m$^{1/2}$×s)]	0.1 to 10^3
Piezogravitic constant	$g = g_{16} = g_{34}$ [kg/m^2]	10^5 to 10^{10}
Piezocogravitic coefficient	$f = f_{16} = f_{34}$ [s^{-1}]	10^{-16} to 10^{-8}
Dielectric permittivity coefficient (electric constant)	$\varepsilon = \varepsilon_{11} = \varepsilon_{33}$ [s^2/m^2]	10^{-10} to 10^{-8}
Magnetic permeability coefficient (magnetic constant)	$\mu = \mu_{11} = \mu_{33}$ [-]	10^{-6} to 10^{-3}
Electromagnetic constant	$\alpha = \alpha_{11} = \alpha_{33}$ [s/m]	10^{-16} to 10^{-12}
Gravitic constant (gravitoelectric permittivity coefficient)	$\gamma = \gamma_{11} = \gamma_{33}$ [kg×s^2/m^3]	10^{10} to 10^{11}
Cogravitic constant (gravitomagnetic permeability coefficient)	$\eta = \eta_{11} = \eta_{33}$ [m/kg]	10^{-28} to 10^{-27}
Gravitocogravitic constant.	$\vartheta = \vartheta_{11} = \vartheta_{33}$ [s/m]	10^{-16} to 10^{-12}
Gravitoelectric constant (electrogravitic constant)	$\zeta = \zeta_{11} = \zeta_{33}$ [kg$^{1/2}$×s^2/m$^{5/2}$]	10^{-8} to 10^{-2}
Cogravitoelectric constant (electrocogravitic constant)	$\xi = \xi_{11} = \xi_{33}$ [s/(kg$^{1/2}$×m$^{1/2}$)]	10^{-45} to 10^{-40}
Gravitomagnetic constant (magnetogravitic constant)	$\beta = \beta_{11} = \beta_{33}$ [kg$^{1/2}$×s/m$^{3/2}$]	10^{-6} to 10
Cogravitomagnetic constant (magnetocogravitic constant)	$\lambda = \lambda_{11} = \lambda_{33}$ [m$^{1/2}$/kg$^{1/2}$]	10^{-40} to 10^{-35}

Table 2: The vacuum parameters borrowed from Yavorsky *et al.* [12], where the value of the vacuum elastic constant was borrowed from work by Kiang and Tong [13]. The other possible exchange parameters for the free space (vacuum) such as α_0, ϑ_0, ζ_0, ξ_0, β_0, λ_0, were theoretically evaluated in the first approximation. This means that the experimentally obtained values of the evaluated vacuum parameters can be even significantly smaller.

Vacuum parameter	Value
Elastic constant	$C_0 = 0.001$ [N/m^2]
Electric constant (dielectric permittivity constant)	$\varepsilon_0 = 0.08854187817 \times 10^{-10}$ [F/m]
Magnetic constant (magnetic permeability constant)	$\mu_0 = 1.25663706144 \times 10^{-6}$ [H/m]
Gravitic constant (gravitoelectric permittivity coefficient)	$\gamma_0 = 1.498334 \times 10^{10}$ [kg×s^2/m^3]
Cogravitic constant (gravitomagnetic permeability coefficient)	$\eta_0 = 0.0742592 \times 10^{-26}$ [m/kg]
Newtonian gravitational (gravitoelectric) constant	$G_0 = 1/\gamma_0 = 0.667408 \times 10^{-10}$ [m^3/(kg×s^2)]
Cogravitational (gravitomagnetic) constant	$M_0 = 1/\eta_0 = 13.46635 \times 10^{26}$ [kg/m]
Speed of light	$C_L = (G_0 M_0)^{1/2} = (\gamma_0 \eta_0)^{-1/2}$ $= (\varepsilon_0 \mu_0)^{-1/2} = 2.997924 \times 10^8$ [m/s]
Electromagnetic exchange constant	$\alpha_0 \sim < 10^{-16}$ [s/m]
Gravitocogravitic exchange constant	$\vartheta_0 \sim < 10^{-16}$ [s/m]
Gravitoelectric exchange constant	$\zeta_0 \sim 10^{-8}$ [kg$^{1/2}$×s^2/m$^{5/2}$]
Cogravitoelectric exchange constant	$\xi_0 \sim 10^{-45}$ [s/(kg$^{1/2}$×m$^{1/2}$)]
Gravitomagnetic exchange constant	$\beta_0 \sim 10^{-6}$ [kg$^{1/2}$×s/m$^{3/2}$]
Cogravitomagnetic exchange constant	$\lambda_0 \sim 10^{-40}$ [m$^{1/2}$/kg$^{1/2}$]

It is also possible to analogically treat the gravitational and cogravitational subsystems. The exchange parameter between these two subsystems can be evaluated by the gravitocogravitic constant ϑ in table1. Therefore, the exchange speed for this case can be calculated as follows:

$$V_\vartheta = \frac{1}{\vartheta} \qquad (10)$$

For the gravitocogravitic constant ϑ, it is possible to require the following inequality for speeds (8) and (10): $V_\vartheta > V_{GC}$ because it is also necessary to require that the following inequality should fulfill $\vartheta^2 < \gamma\eta$. Indeed, it is expected that $V_\vartheta >> V_{GC}$ and $\vartheta^2 << \gamma\eta$ must also occur for a real solid.

In a vacuum, it is well-known that an electromagnetic wave propagates with the speed of light, C_L. A gravitocogravitic wave (gravitational wave) also propagates with the same speed in a vacuum. This statement was predicted by Einstein [5] in 1916 and experimentally confirmed in 2016 [4]. Using subscript "0" for all the vacuum material parameters listed in table 2 ([12],[13]), it is possible to write down the following formula for the speed of light in a vacuum:

$$C_L = \frac{1}{\sqrt{\varepsilon_0\mu_0}} = \frac{1}{\sqrt{\gamma_0\eta_0}} \quad (11)$$

These vacuum parameters ε_0, μ_0, γ_0, η_0 can be also calculated with Planck's quantum parameters. This is shown in table 3. It is necessary to state that an electromagnetic wave in a vacuum represents a two-potential wave because in this case there are the electrical and magnetic subsystems characterized by the electrical and magnetic potentials. It is also possible to assume that there is an exchange between these two subsystems when an electromagnetic wave propagates in the free space (vacuum). For this exchange between these two subsystems, it is natural to use the exchange parameter such as the vacuum electromagnetic constant α_0. Concerning the gravitocogravitic wave (gravitational wave) propagating in a vacuum, it also represents a two-potential wave because there are the gravitational and cogravitational subsystems characterized by the gravitational and cogravitational potentials. Therefore, it is natural to use the vacuum gravitocogravitic constant ϑ_0 for the exchange between these two subsystems. These vacuum exchange parameters α_0 and ϑ_0 are evaluated in the second table. However, they are not present in the third table because nobody has demonstrated that these vacuum exchange parameters can be derived with Planck's quantum parameters. In a vacuum, the propagation of an electromagnetic wave couples the electrical and magnetic subsystems. This coupling determines the electromagnetic wave propagation due to an energy exchange between two subsystems. Therefore, the vacuum exchange parameters α_0 must exist even it is very small. The same can be stated for the coupling between the gravitational and cogravitational subsystems resulting in the gravitocogravitic wave (gravitational wave) propagation in a vacuum. Therefore, the vacuum exchange parameter ϑ_0 must be also taken into account. It is also naturally assumed that $V_{\alpha 0} > C_L$ and $V_{\vartheta 0} > C_L$ because it is assumed that $\alpha_0^2 < \varepsilon_0\mu_0$ and $\vartheta_0^2 < \gamma_0\eta_0$, respectively.

Table 3: The expressions of the vacuum parameters ε_0, μ_0, γ_0, η_0 in dependence on Planck's quantum parameters.

Parameter	Value or formula
Planck's force	$F_{Planck} = 1.21027 \times 10^{44}$ [N]
Planck's length	$L_{Planck} = 1.61623 \times 10^{-35}$ [m]
Planck's mass	$M_{Planck} = 2.17651 \times 10^{-8}$ [kg]
Planck's charge	$Q_{Planck} = 1.875545 \times 10^{-18}$ [C]
Planck's speed = Speed of light	$V_{Planck} = C_L = 2.997924 \times 10^{8}$ [m/s]
Planck's time	$T_{Planck} = L_{Planck}/V_{Planck} = 5.39116 \times 10^{-44}$ [s]
Electric constant (dielectric permittivity constant)	$\varepsilon_0 = \frac{1}{4\pi}\frac{1}{F_{Planck}}\left(\frac{Q_{Planck}}{L_{Planck}}\right)^2$
Magnetic constant (magnetic permeability constant)	$\mu_0 = 4\pi F_{Planck}\left(\frac{T_{Planck}}{Q_{Planck}}\right)^2$
Newtonian gravitational (gravitoelectric) constant	$G_0 = \frac{1}{\gamma_0} = F_{Planck}\left(\frac{L_{Planck}}{M_{Planck}}\right)^2$
Cogravitational (gravitomagnetic) constant	$M_0 = \frac{1}{\eta_0} = \frac{1}{F_{Planck}}\left(\frac{M_{Planck}}{T_{Planck}}\right)^2$

Therefore, the corresponding vacuum exchange speeds can be evaluated as follows:

$$V_{\alpha 0} = \frac{1}{\alpha_0} \tag{12}$$

$$V_{\vartheta 0} = \frac{1}{\vartheta_0} \tag{13}$$

Using (5) and (6), one can also find that there are additional two exchange speeds. For a solid, these speeds can be denoted by Λ_1 and Λ_2 in formulae (14) and (15) below. They can be also compared with the speed of light in a vacuum (11) representing a two-potential system discussed above. However, these speeds are for propagations of two different four-potential systems. Each of two four-potential systems already incorporates the electrical, magnetic, gravitational, and cogravitational subsystems to demonstrate a wave motion caused by a coupling of these four subsystems characterized by the following four potentials: the electrical, magnetic, gravitational, and cogravitational potentials. The exchange speed Λ_1 depends on the following exchange parameters listed in table 1: the gravitoelectric constant ζ and the cogravitomagnetic constant λ. The gravitoelectric constant ζ represents an exchange parameter between the electrical and gravitational subsystems. The cogravitomagnetic constant λ represents an exchange parameter between the magnetic and cogravitational subsystems. This means that the exchange speed Λ_1 is for a system that incorporates all four subsystems such as the electrical, magnetic, gravitational, and cogravitational subsystems. Analogically, the exchange speed Λ_2 depends on the following exchange parameters listed in table 1: the cogravitoelectric constant ξ and the gravitomagnetic constant β. The first material parameter represents an exchange between the electrical and cogravitational subsystems. And the second parameter represents an exchange between the magnetic and gravitational subsystems. So, this is also a four-potential wave.

These additional two exchange speeds read as follows:

$$\Lambda_1 = \frac{1}{\sqrt{\zeta\lambda}} \rightarrow (10^{11} \div 10^{16})C_L \tag{14}$$

$$\Lambda_2 = \frac{1}{\sqrt{\xi\beta}} \rightarrow (10^{12} \div 10^{17})C_L \tag{15}$$

For a vacuum, it is also possible to introduce the corresponding four-potential waves propagating with speeds Λ_{01} and Λ_{02} due to an exchange among the four subsystems such as the electrical, magnetic, gravitational, and cogravitational subsystems. Using the subscript "0" for the corresponding vacuum parameters, it is possible to compare these speeds with the speed of light in a vacuum. These speeds read:

$$\Lambda_{01} = \frac{1}{\sqrt{\zeta_0\lambda_0}} \rightarrow (10^{11} \div 10^{16})C_L \tag{16}$$

$$\Lambda_{02} = \frac{1}{\sqrt{\xi_0 \beta_0}} \rightarrow (10^{12} \div 10^{17}) C_L \qquad (17)$$

The vacuum material parameters ζ_0, λ_0, ξ_0, and β_0 are listed and evaluated in the second table. The values for the vacuum parameters are given in the first approximation because nobody has evaluated them before. It is expected that their values can be precisely measured in space experiments and then their values can be also calculated with Planck's quantum parameters listed in the third table.

It is also possible to discuss expression (5) representing the denominator in formula (3) for the coupling coefficient CEMGCMC. The first term consisting of two cofactors in (5) couples the material parameters ε, μ, γ, η and their corresponding exchange parameters α and ϑ. However, expression (5) can be written in a regrouped form, the first term in which can already couple the material parameters ε, μ, γ, η with the exchange parameters ξ and β instead of α and ϑ. This form reads as follows:

$$B_2 = (\varepsilon\eta - \xi^2)(\mu\gamma - \beta^2) + (\alpha\vartheta - \lambda\zeta)^2 - (\vartheta^2\varepsilon\mu + \alpha^2\gamma\eta + \lambda^2\varepsilon\gamma + \zeta^2\mu\eta) + 2(\gamma\alpha\xi\lambda + \eta\alpha\beta\zeta + \varepsilon\beta\lambda\vartheta + \mu\zeta\xi\vartheta - \zeta\xi\beta\lambda - \alpha\beta\xi\vartheta) \qquad (18)$$

In addition, expression (5) can be anew regrouped to have the coupling of the material parameters ε, μ, γ, η with the exchange parameters ζ and λ instead of α and ϑ. This form is

$$B_2 = (\varepsilon\gamma - \zeta^2)(\mu\eta - \lambda^2) + (\alpha\vartheta - \beta\xi)^2 - (\vartheta^2\varepsilon\mu + \alpha^2\gamma\eta + \xi^2\mu\gamma + \beta^2\varepsilon\eta) + 2(\gamma\alpha\xi\lambda + \eta\alpha\beta\zeta + \varepsilon\beta\lambda\vartheta + \mu\zeta\xi\vartheta - \zeta\xi\beta\lambda - \alpha\zeta\lambda\vartheta) \qquad (19)$$

Three different forms (5), (18), and (19) manifest that exchange speeds (14) and (15) are not less important than the exchange speeds (9) and (10). The following section obtains the exchange terms to demonstrate that the complicated coupling coefficient (3) can be decomposed into several already known coupling coefficients that are more simply.

3 The exchange terms

The coupling coefficient CEMGCMC (3) can be introduced in the following form:

$$K_{emgc}^2 = K_{em}^2 + K_{gc}^2 + K_{ex0}^2 \qquad (20)$$

where

$$K_{em}^2 = \frac{\mu e^2+\varepsilon h^2-2\alpha eh}{C(\varepsilon\mu-\alpha^2)} = \frac{e(e\mu-h\alpha)-h(e\alpha-h\varepsilon)}{C(\varepsilon\mu-\alpha^2)} \quad (21)$$

$$K_{gc}^2 = \frac{\eta g^2+\gamma f^2-2\vartheta gf}{C(\gamma\eta-\vartheta^2)} = \frac{g(g\eta-f\vartheta)-f(g\vartheta-f\gamma)}{C(\gamma\eta-\vartheta^2)} \quad (22)$$

Definitions (21) and (22) stand for the coefficient of the magnetoelectromechanical coupling (CMEMC) and the coefficient of the gravitocogravitomechanical coupling (CGCMC), respectively. All the material parameters present in (21) and (22) are listed in table 1. The coupling coefficient CMEMC (21) was previously studied in paper [14]. It is clearly seen in (21) and (22) that the coupling coefficients (21) and (22) have the same form and therefore, they can be studied in the same way.

The last term in expression (20) represents an exchange term that can be obtained with the following formula:

$$K_{ex0}^2 = K_{emgc}^2 - K_{em}^2 - K_{gc}^2 = \frac{B_1(\varepsilon\mu-\alpha^2)(\gamma\eta-\vartheta^2)-B_2(\mu e^2+\varepsilon h^2-2\alpha eh)(\gamma\eta-\vartheta^2)-B_2(\eta g^2+\gamma f^2-2\vartheta gf)(\varepsilon\mu-\alpha^2)}{C(\varepsilon\mu-\alpha^2)(\gamma\eta-\vartheta^2)B_2} \quad (23)$$

Following results of paper [14], the coupling coefficients (21) and (22) can be then decomposed into the following corresponding forms:

$$K_{em}^2 = K_e^2 + K_m^2 + K_{ex1}^2 \quad (24)$$

$$K_{gc}^2 = K_g^2 + K_f^2 + K_{ex2}^2 \quad (25)$$

The first term in expression (24) is called the coefficient of the electromechanical coupling K_e^2 (CEMC). This is a very important characteristic for a purely piezoelectric material. It is defined by

$$K_e^2 = \frac{e^2}{C\varepsilon} \quad (26)$$

The second term in expression (24) is called the coefficient of the magnetomechanical coupling K_m^2 (CMMC). It represents a very important characteristic for a purely piezomagnetic material and is defined by the following form:

$$K_m^2 = \frac{h^2}{C\mu} \tag{27}$$

The third term in expression (24) represents an exchange term defined by the following expression [14]:

$$K_{ex1}^2 = K_{em}^2 - K_e^2 - K_m^2 = \frac{\alpha^2(\mu e^2 + \varepsilon h^2) - 2\alpha\varepsilon\mu e h}{C\varepsilon\mu(\varepsilon\mu - \alpha^2)} \tag{28}$$

The first term in (25) is called the coefficient of the gravitomechanical coupling K_g^2 (CGMC) and defined by

$$K_g^2 = \frac{g^2}{C\gamma} \tag{29}$$

The second term in (25) is called the coefficient of the cogravitomechanical coupling K_f^2 (CCMC) and defined by

$$K_f^2 = \frac{f^2}{C\eta} \tag{30}$$

The third term (exchange term) in (25) is defined by

$$K_{ex2}^2 = K_{gc}^2 - K_g^2 - K_f^2 = \frac{\vartheta^2(\eta g^2 + \gamma f^2) - 2\vartheta\gamma\eta g f}{C\gamma\eta(\gamma\eta - \vartheta^2)} \tag{31}$$

Therefore, the nondimensional parameter K_{emgc}^2 (3) called the coefficient of the electromagnetogravitocogravitomechanical coupling (CEMGCMC) can be written in the following final form:

$$K_{emgc}^2 = K_e^2 + K_m^2 + K_g^2 + K_f^2 + K_{ex}^2 \tag{32}$$

where

$$K_{ex}^2 = K_{emgc}^2 - K_e^2 - K_m^2 - K_g^2 - K_f^2 = K_{ex0}^2 + K_{ex1}^2 + K_{ex2}^2 = \frac{B_1\varepsilon\mu\gamma\eta - B_2\gamma\eta(\mu e^2+\varepsilon h^2) - B_2\varepsilon\mu(\eta g^2+\gamma f^2)}{C\varepsilon\mu\gamma\eta B_2} \quad (33)$$

In expression (33), the complicated parameters B_1 and B_2 are defined by expressions (4) and (5), respectively. However, the parameter B_2 can be used in equivalent form (18) or (19). It is possible to state that form (32) of the CEMGCMC K_{emgc}^2 (3) is convenient for further analysis. It is clearly seen that the nondimensional material parameters K_e^2 (26), K_m^2 (27), K_g^2 (29), and K_f^2 (30) are quite simple and do not depend on any of the six exchange material parameters α, ϑ, ζ, λ, ξ, and β listed in table 1. In contrast, the exchange parameter K_{ex}^2 (33) in (32) is quite complicated and depends on all the exchange material parameters. There is an interest in investigations of behavior of the CEMGCMC K_{emgc}^2 (32) in dependence on the exchange parameters α, ϑ, ζ, λ, ξ, and β. It is clearly seen in (32) that this problem reduces to the investigations of the exchange parameter K_{ex}^2 (33) as the following function: $K_{ex}^2(\alpha,\vartheta,\zeta,\lambda,\xi,\beta)$. So, it is useful to write down the following equalities:

$$K_{ex}^2(\alpha = 0, \vartheta = 0, \zeta = 0, \lambda = 0, \xi = 0, \beta = 0) = 0 \quad (34)$$

$$K_{emgc0}^2 = K_{emgc}^2\left(K_e^2, K_m^2, K_g^2, K_f^2, K_{ex}^2 = 0\right) = K_e^2 + K_m^2 + K_g^2 + K_f^2 \quad (35)$$

It is possible to treat a solid, for which there are $K_e^2 \neq 0$, $K_m^2 \neq 0$, $K_g^2 \neq 0$, and $K_f^2 \neq 0$. In general, $K_e^2 > 0$ and $K_m^2 > 0$ occur. It is also possible to require that $K_g^2 > 0$ and $K_f^2 > 0$. Therefore there is $K_{emgc0}^2 > 0$ in (35). However there can be the following interesting case:

$$K_{ex}^2(\alpha \neq 0, \vartheta \neq 0, \zeta \neq 0, \lambda \neq 0, \xi \neq 0, \beta \neq 0) = 0 \quad (36)$$

For case (36) there can be $K_{emgc0}^2 > 0$ in (35), too. It is natural that the exchange parameters α, ϑ, ζ, λ, ξ, and β are very small. In comparison with the other material parameters listed in table 1, these very small parameters will change their values more dramatically for a solid under external perturbations and changes in some boundary conditions. Therefore, it is possible to utilize three dimensionless variables ($\alpha^2\vartheta^2/\varepsilon\mu\gamma\eta$), ($\zeta^2\lambda^2/\varepsilon\mu\gamma\eta$), and ($\xi^2\beta^2/\varepsilon\mu\gamma\eta$) instead of the following six variables possessing physical dimensions: α, ϑ, ζ, λ, ξ, and β. Therefore, it is possible to assume that when any of three dimensionless variables is very slightly changed, the variable's numerator has more significant contribution than the variable's denominator. As a result, it is more convenient to deal with the following three functions depending on one of three dimensionless variables instead of a function of the six variables:

$$K_{ex}^2(\alpha,\vartheta,\zeta,\lambda,\xi,\beta) \rightarrow K_{ex}^2\left(\frac{\alpha^2\vartheta^2}{\varepsilon\mu\gamma\eta}\right) \quad (37)$$

$$K_{ex}^2(\alpha,\vartheta,\zeta,\lambda,\xi,\beta) \rightarrow K_{ex}^2\left(\frac{\xi^2\beta^2}{\varepsilon\mu\gamma\eta}\right) \quad (38)$$

$$K_{ex}^2(\alpha,\vartheta,\zeta,\lambda,\xi,\beta) \rightarrow K_{ex}^2\left(\frac{\zeta^2\lambda^2}{\varepsilon\mu\gamma\eta}\right) \quad (39)$$

where

$$0 < \frac{\alpha^2\vartheta^2}{\varepsilon\mu\gamma\eta} < 1,\ 0 < \frac{\alpha^2}{\varepsilon\mu} < 1,\ 0 < \frac{\vartheta^2}{\gamma\eta} < 1 \quad (40)$$

$$0 < \frac{\xi^2\beta^2}{\varepsilon\mu\gamma\eta} < 1,\ 0 < \frac{\xi^2}{\varepsilon\eta} < 1,\ 0 < \frac{\beta^2}{\mu\gamma} < 1 \quad (41)$$

$$0 < \frac{\zeta^2\lambda^2}{\varepsilon\mu\gamma\eta} < 1,\ 0 < \frac{\zeta^2}{\varepsilon\gamma} < 1,\ 0 < \frac{\lambda^2}{\mu\eta} < 1 \quad (42)$$

It is worth mentioning that functions (37), (38), and (39) correspond to equivalent records (5), (18), and (19), respectively. It is expected that for $\alpha < 0$, $\vartheta < 0$, $\zeta < 0$, $\lambda < 0$, $\xi < 0$, and $\beta < 0$ there is only case (34). However, for $\alpha > 0$, $\vartheta > 0$, $\zeta > 0$, $\lambda > 0$, $\xi > 0$, and $\beta > 0$ there can be already both cases (34) and (36). This can be similar to the significantly more simplified case of $K_{ex1}^2(\alpha) \rightarrow K_{ex1}^2(\alpha^2/\varepsilon\mu)$ (28) treated in paper [14] for a piezoelectromagnetic solid. Theoretical work [14] has demonstrated that the exchange parameter K_{ex1}^2 between two zero values $K_{ex1}^2(\alpha = 0) = 0$ and $K_{ex1}^2(\alpha > 0) = 0$ can have only a negative sign that can significantly decrease the value of the CMEMC K_{em}^2

(21). The results of paper [14] can be readily applied for the dependence of the CGCMC K_{gc}^2 (22) on the exchange parameter K_{ex2}^2 (31). For the case of function $K_{gc}^2(K_{ex2}^2)$ that means the case of function $K_{gc}^2(\vartheta) \to K_{gc}^2(\vartheta^2/\gamma\eta)$, the set of material parameters $\{\rho, C, e, h, \varepsilon, \mu, \alpha\}$ in paper [14] must be replaced by the set of the corresponding material parameters $\{\rho, C, g, f, \gamma, \eta, \vartheta\}$. For a concrete solid, a complete set of all the material parameters listed and evaluated in table 1 is absent because there are only evaluations of some of small parameters such as ζ, λ, ξ, and β. Some reasons of this horrible absence are discussed in the following section.

4 Discussions

It is a pleasure to deal with a complete set of measured material parameters listed in table 1 for a concrete solid but not with the evaluated values given in the table that can correspond to a majority of corresponding solids. To have measured material parameters $\{\rho, C, e, h, g, f, \varepsilon, \mu, \gamma, \eta, \alpha, \vartheta, \zeta, \lambda, \xi, \beta\}$ listed in table 1 for several concrete solids can be useful for many engineering problems concerning constructions of models of acoustic wave propagation managed by the free surface of a solid, a common interface between two dissimilar solids, a waveguide consisting of thin solid films (plates). For this purpose, it is convenient that the material parameters must be measured and introduced in Nye's tensor notations [15]. This century is positioned as the century of gravity, namely the century for development of gravitational phenomena and their incorporation to electrical and magnetic phenomena. Therefore, gravitational engineers are called to the field of the gravitational engineering. This is like the last century representing the century for the electrical engineering.

In the last century, the piezoelectric effect was recognized as a weak effect that can be neglected when acoustic wave propagation in solids are studied. However, Bleustein [16] and Gulyaev [17] have simultaneously discovered to the end of the 1960s that this weak affect can cause an instability of the shear-horizontal bulk acoustic wave (SH-BAW) leading to the existence of the shear-horizontal surface acoustic wave (SH-SAW) in piezoelectrics. Today, piezoelectrics are important materials in signal processing technologies because various technical devices based on electroacoustic waves (i.e. piezoelectric waves) [18, 19] are incorporated in the modern global communication industry on this planet Earth. The wave properties of the piezoelectric materials are extensively studied during the last half-century. The reader can read books [18] and [19] on the acoustic wave propagation in crystals. The properties of hundreds of acoustic crystals are combined in book [20] that is convenient because the book provides sets of measured material parameters $\{\rho, C, e, \varepsilon\}$ for piezoelectrics with different crystal symmetries. Acoustic waves can also propagate in piezomagnetic crystals. However there is no book that combined the piezomagnetic material parameters $\{\rho, C, h, \mu\}$ for crystals with different symmetries. Papers [21] and [22] provide the material parameters $\{\rho, C, h, \mu\}$ for some interesting piezomagnetics.

Piezoelectrics together with piezomagnetics are frequently used to model smart piezoelectromagnetic materials also called the magnetoelectroelastics. These materials possess average properties, i.e. have both the piezoelectric and piezomagnetic effects. This results in the existence of a weak magnetoelectric effect in the smart materials. There is no book that combines acoustic properties of the piezoelectromagnetics, for instance, sets of the measured material parameters $\{\rho, C, e, h, \varepsilon, \mu, \alpha\}$. Moreover, only in 2007 Melkumyan [23] has discovered several SH-SAWs that can propagate in the piezoelectromagnetics. This is almost forty years after the discovery of the SH-SAW by Bleustein [16] and Gulyaev [17]. Following work [23], book [24] has discovered additional seven new SH-SAWs. Book [24] has demonstrated that the weak magnetoelectric effect can also cause the acoustic wave propagation, see the fifth new SH-SAW in equation (163) of the book results. And there is only single review paper [25] on the wave propagation in the smart piezoelectromagnetic materials. A study of wave propagation in some strong magnetoelectric materials with the known material parameters $\{\rho, C, e, h, \varepsilon, \mu, \alpha\}$ can be found in paper [26]. When a set of the corresponding material parameters $\{\rho, C, g, f, \gamma, \eta, \vartheta\}$ is used instead of the set of material parameters $\{\rho, C, e, h, \varepsilon, \mu, \alpha\}$, the wave propagation can be also studied. However, nobody has still studied such materials. The acoustic wave propagation transmits energy. Therefore, the gravitational phenomena due to energy transmission must be also taken into account when acoustic wave propagation in studied in the piezoelectromagnetics. As a result, the studied system [1] has already the mechanical, electrical, magnetic, gravitational, and cogravitational subsystems. To disrobe such complicated system, the set of material parameters $\{\rho, C, e, h, g, f, \varepsilon, \mu, \gamma, \eta, \alpha, \vartheta, \zeta, \lambda, \xi, \beta\}$ listed in table 1 must be used. At the beginning of the 1990s, Li's research group ([27],[28],[29]) has evaluated the material parameters $\{\gamma, \eta\}$ for a superconducting solid. In 2016, Füzfa [8] has found how to evaluate some of the exchange material parameters $\{\zeta, \lambda, \xi, \beta\}$ at the earth conditions and found them very weak. In this case, the exchange material parameters $\{\alpha, \vartheta, \zeta, \lambda, \xi, \beta\}$ are very small but it is necessary to demonstrate in further work that they or some of them can cause the acoustic wave propagation and therefore, cannot be neglected in calculations. Moreover, these weak material parameters must be precisely measured and for this purpose, the corresponding measurement technique must be developed.

For new communication era based on some gravitational phenomena, the measured vacuum material parameters $\{\varepsilon_0, \mu_0, \gamma_0, \eta_0, \alpha_0, \vartheta_0, \zeta_0, \lambda_0, \xi_0, \beta_0\}$ must be also known. The vacuum material parameters $\{\varepsilon_0, \mu_0, \gamma_0, \eta_0\}$ are well-known and their values are listed in table 2. However, the rest vacuum parameters $\{\alpha_0, \vartheta_0, \zeta_0, \lambda_0, \xi_0, \beta_0\}$ represent exchange constants that are introduced in this paper and evaluated in table 2. It is expected that their exact values can be obtained in different space experiments. It is well-known that $\alpha^2 < \varepsilon\mu$ ([10],[11]) should occur for any piezoelectromagnetics for a system stability. In general, $\alpha^2 << \varepsilon\mu$ occurs. It is possible to assume that $\alpha_0^2 << \varepsilon_0\mu_0$ must also occur because some exchange between the electrical and magnetic subsystems must exist during the propagation of an electromagnetic wave in a vacuum. Concerning the gravitocogravitic constant ϑ_0, the inequality $\vartheta_0^2 << \gamma_0\eta_0$ must also be assumed for a gravitocogravitic wave (gravitational wave) propagating with the speed of light (11) in a vacuum. It is possible that the exchange parameters $\{\alpha_0, \vartheta_0\}$ can be too negligible to take into account. However, it is possible to write down the following:

$$C_L = \frac{1}{\sqrt{\varepsilon_0\mu_0 - \alpha_0^2}} \sim \frac{1}{\sqrt{\gamma_0\eta_0 - \vartheta_0^2}} \quad (43)$$

The other vacuum exchange parameters $\{\zeta_0, \lambda_0, \xi_0, \beta_0\}$ respectively representing the gravitoelectric, cogravitomagnetic, cogravitoelectric, and gravitomagnetic constants can be also extremely small similar to the parameters $\{\alpha_0, \vartheta_0\}$ discussed above. It is well-known that a massive body can continuously eject electromagnetic and gravitational waves into a vacuum. As a result, the free space (a vacuum) is filled with these types of the fast waves from many bodies. This extremely fast exchange among the four subsystems (electrical, magnetic, gravitational, and cogravitational subsystems) can be evaluated by formulae (16) and (17) for speeds Λ_{01} and Λ_{02}, respectively.

The interaction between the electromagnetic waves and gravitation is well-known for today. The most popular example of this interaction is the effect of captivation of the electromagnetic waves by a black hole located at the center of any galaxy. It is well-known that a black hole can capture an electromagnetic wave by the way that the electromagnetic wave cannot escape. It is assumed that in order to capture any electromagnetic wave propagating with the speed of light in a vacuum, the interaction between this electromagnetic wave and gravitation must be very fast, i.e. significantly faster than any of speed of light. This can mean both the electromagnetic wave and the gravitational wave (both propagating with the speed of light in a vacuum) represent static systems for the interaction processes existing among the electric, magnetic, gravitational, and cogravitational subsystems. This can mean that the exchange signals look like nearly instant (i.e. very high-speed) processes.

It is necessary here to state that the size of our Universe is approximately 100 billion light years, i.e. 100 Gly (Gigalight year). 1 meter is equal to $1.0570008340246 \times 10^{-16}$ light year, or $1.0577248071986 \times 10^{-25}$ Gly. The shape of a Universe is assumed to be a sphere like a bubble. It is possible to estimate that the speeds Λ_{01} and Λ_{02} for a vacuum cannot exceed the limit value of $C_U \sim 10^{27}$ ms^{-1}. It is also expected that the speeds Λ_1 (14) and Λ_2 (15) in a solid can differ from the corresponding vacuum speeds Λ_{01} (16) and Λ_{02} (17). However, a liner size of any solid in our Universe in any direction is too negligible in comparison with the size of our Universe. For instance, the size of our Galaxy called Milky Way with a black hole at the galactic center is only by about 100,000 light years, i.e. six orders smaller than the linear size of our Universe. So, it is expected that a linear size of any solid, solid planet, gas-like planet, star, and even whole Galaxy cannot represent any screen for such (artificially) generated signals travelling with the speeds Λ_{01} and Λ_{02}. Such signal can immediately and simultaneously reach any point inside of our Universe as soon as it is generated at any spot of our Universe. Indeed, it is horrible to communicate with the purely electromagnetic waves (two-potential waves) propagating with speed C_L across the Solar System. For instance, a purely electromagnetic signal can reach planet Mars from Earth in ~ 3 to 20 minutes. Generated four-potential signals propagating with the speeds $\Lambda_{01} \gg C_L$ and $\Lambda_{02} \gg C_L$ can give our civilization an opportunity of interplanetary, interstellar, intergalactic communications without any significant delays.

5 Conclusion

This report has studied the coefficient of the electromagnetogravitocogravitomechanical coupling (CEMGCMC) K^2_{emgc}. This coefficient is quite complicated because it couples the mechanical, electrical, magnetic, gravitational, and cogravitational subsystems. This theoretical work has demonstrated that the CEMGCMC K^2_{emgc} (3) can be introduced in a convenient form that combines four simplest coupling coefficients (32) plus a complicated exchange term (33). This complicated exchange term consists of several other exchange terms and combines all dependence on the small exchange material parameters α, ϑ, ζ, λ, ξ, and β listed in table 1. It was discussed that the exchange term can significantly decrease the value of the CEMGCMC K^2_{emgc} for small values of α, ϑ, ζ, λ, ξ, and β. These small material parameters for a solid and the possible corresponding parameters α_0, ϑ_0, ζ_0, λ_0, ξ_0, and β_0 for a vacuum were also discussed. It was evaluated and discussed that speeds (16) and (17) for the propagation of four-potential systems can be significantly faster than the speed of light (11) in a vacuum, with which both the two-potential electromagnetic wave and the two-potential gravitocogravitic (gravitational) wave can propagate. Also, this theoretical work can provoke some development of the gravitational engineering research arena for new communication era based on some gravitational phenomena.

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