HADRONIC JOURNAL 43, 171 - 186 (2020)
DOI 10.29083/HJ.43.02.2020

RELATIVE MATERIAL PARAMETERS αE, αH, ϑG, ϑF, ξE, ξF, βH, βG, ζE, ζG, λH, AND λF FOR MAGNETOELECTROELASTICS TO MODEL ACOUSTIC WAVE PROPAGATION INCORPORATING GRAVITATIONAL PHENOMENA

Aleksey Anatolievich Zakharenko
International Institute of Zakharenko Waves (IIZWs)
660014, ul. Chaikovskogo, 20-304, Krasnoyarsk, Russia
aazaaz@inbox.ru

Received January 9, 2020

Abstract

Regarding solid materials of symmetry class 6 *mm*, it is natural to deal with mechanical, electrical, magnetic, gravitational, and cogravitational properties. In addition to the electromagnetic α and gravitocogravitic ϑ constants, the incorporation of gravitational phenomena for these smart magnetoelectroelastics adds the gravitoelectric ζ, cogravitoelectric ξ, gravitomagnetic β, and cogravitomagnetic λ constants. All of them contribute to the value of the coefficient of the electromagnetogravitocogravitomechanical coupling (CEMGCMC). The CEMGCMC represents one of very important material characteristics because the dynamic characteristics such as the bulk and surface acoustic wave speeds depend on it. Therefore, it requires experimental determinations of the α, ϑ, ζ, ξ, β, and λ. In addition to the well-known relative parameters α_E and α_H, this report introduces the relative material parameters ϑ_G, ϑ_F, ξ_E, ξ_F, β_H, β_G, ζ_E, ζ_G, λ_H, and λ_F, where the subscripts "*E*", "*H*", "*G*", "*F*" relate to the electrical, magnetic, gravitational, and cogravitational subsystems, respectively. It is expected that their measurements can be preferable due to the successful measurements of α_E and α_M during the last six decades. The knowledge of the complete set of the material parameters for different magnetoelectroelastics can provide a class of commercially fitting materials to constitute various technical devices with suitable characteristics. This can actually contribute to the development of infrastructure for signal processing based on the new fast waves that can propagate in the solids at the speeds $\Lambda_1 = (\zeta\lambda)^{-1/2} \rightarrow \sim 10^{13}C_L$ and $\Lambda_2 = (\xi\beta)^{-1/2} \rightarrow \sim 10^{13}C_L$, where C_L is the light speed in a vacuum. Also, the new fast waves can propagate in a vacuum at the speeds $\Lambda_{01} = (\zeta_0\lambda_0)^{-1/2} \rightarrow \sim 10^{13}C_L$ and $\Lambda_{02} = (\xi_0\beta_0)^{-1/2} \rightarrow \sim 10^{13}C_L$. These speeds Λ_{01} and Λ_{02} are already apt for development of the instant interplanetary communication.

Keywords: Continuous media; Magnetoelectric and gravitational effects; Four potential coupling problem; Exchange material parameters.

Copyright © 2020 by Hadronic Press, Inc., Palm Harbor, FL 34684, USA

1 Introduction

The recently developed theory [1, 2] of the acoustic wave propagation coupled with the electrical, magnetic, gravitational, and cogravitational potentials (i.e. the four-potential acoustic wave) has provided some theoretical, mathematical, experimental, and engineering problems. Successful developments towards resolving all these problems can result in appearance of infrastructure, with which it will be possible to have the instant interplanetary communication based on some gravitational phenomena. This communication is possible because theory [1] has introduced two new fast waves that can propagate in both solids and a vacuum at speeds thirteen orders faster than the speed of light in a vacuum, $C_L = (\varepsilon_0\mu_0)^{-1/2} \sim (\gamma_0\eta_0)^{-1/2} \sim 3 \times 10^8$ [m/s]. Here it is worth noting that Abbott *et al.* [3] have found in 2016 that the gravitational waves can also propagate in a vacuum with the speed of light $C_L \sim (\gamma_0\eta_0)^{-1/2}$. Therefore, both the electromagnetic and gravitational waves are unsuitable for the instant interplanetary communication. These new fast speeds $\Lambda_{01} = (\zeta_0\lambda_0)^{-1/2} \rightarrow 10^{13}C_L$ and $\Lambda_{02} = (\xi_0\beta_0)^{-1/2} \rightarrow 10^{13}C_L$ for signal processing are already enough for the instant interplanetary (interstellar and even intergalactic) communication. For this purpose, it is necessary to know measured values of the following parameters for a vacuum: the electric constant ε_0, magnetic constant μ_0, gravitic constant γ_0, cogravitic constant η_0, gravitoelectric constant ζ_0, cogravitoelectric constant ξ_0, gravitomagnetic constant β_0, and cogravitomagnetic constant λ_0.

The measurement tools are currently well-developed for determination of the vacuum parameters ε_0 and μ_0. For a vacuum [4], the magnetic permeability constant (magnetic constant) $\mu_0 = 4\pi \times 10^{-7}$ [H/m] = $1.25663706144 \times 10^{-6}$ [H/m] and the dielectric permittivity constant (electric constant) $\varepsilon_0 = 10^{-7}/(4\pi C_L^2) = 8.854187817 \times 10^{-12}$ [F/m] because $C_L = 2.99782458 \times 10^8$ [m/s]. For solids, the electrical properties are known for many materials [5] and the experimental tools [6] for determination of magnetic properties are also well-developed. There are magnetoelectric solids [7, 8, 9] that possess the magnetoelectric effect characterized by the electromagnetic constant α. The magnetoelectric materials are suitable candidates for spintronics. For the magnetoelectric materials there is the following condition of thermodynamic stability: $\alpha^2 < \varepsilon\mu$ [7, 8], where ε and μ are the electric and magnetic constants for solids, respectively. To enhance the value of the electromagnetic constant α, composite materials are created [7, 8]. However there are hexagonal monocrystals [9] that can commercially compete with the composites. For the solids there is always $\alpha^2 << \varepsilon\mu$ that can be readily rewritten as follows: $V_\alpha >> V_{EM}$, where $V_\alpha = 1/\alpha$ and $V_{EM} = (\varepsilon\mu)^{-1/2}$ stand for the exchange speed and the speed of the electromagnetic wave, respectively. For the solids, the magnetoelectric effect is so small that there is even $V_\alpha >> C_L$. This is an evidence that the exchange speed can be significantly faster than the speed of the electromagnetic wave propagating in a solid or a vacuum.

According to theory [1], the taking into account some gravitational phenomena in the theory of the acoustic wave propagation in the magnetoelectric materials can result in interactions of extra two subsystems (gravitational and cogravitational) with the electrical and magnetic subsystems. This theory uses the centennial postulation by Einstein that any kind of energy (and any change in energy) is coupled with gravitation. In 1916, Einstein [10] has used an analogy between the gravitation and electromagnetism that was first mentioned by Heaviside [11] in 1893. This analogy was studied by many theoreticians. For instance, Jefimenko in his book [12] has studied the gravitation and cogravitation that are also called the gravitoelectricity and gravitomagnetism in the theory of the gravitoelectromagnetism representing the purely gravitational theory. So, it is natural that theory [1] uses the gravitational and cogravitational subsystems. As a result, developed theory [1] leads to the appearance of two new fast waves propagating at the following speeds in the solids: $\Lambda_1 = (\zeta\lambda)^{-1/2}$ and $\Lambda_2 = (\xi\beta)^{-1/2}$, where ζ, λ, ξ, and β are the gravitoelectric, cogravitomagnetic, cogravitoelectric, and gravitomagnetic constants for the solid, respectively. These two exchange speeds can propagate thirteen orders faster than the speed of light, C_L. It is possible to write the following thermodynamic stability condition: $\Lambda_1 >> V_\alpha$ and $\Lambda_2 >> V_\alpha$. Therefore, $\Lambda_1 >> C_L$ and $\Lambda_2 >> C_L$. Also, it is natural to write down for a vacuum: $\Lambda_{01} >> C_L$ and $\Lambda_{02} >> C_L$. These means that the parameters $\{\zeta_0, \xi_0, \beta_0, \lambda_0\}$ for a vacuum and the corresponding material parameters $\{\zeta, \xi, \beta, \lambda\}$ for the solids must be known in order to evaluate the corresponding exchange speeds.

This report offers for the reader to deal with relative material parameters instead of $\{\zeta, \xi, \beta, \lambda\}$ for the solids. These relative material parameters will be introduced in the following section. Each of them is relevant to one of the following aforementioned material parameters for the solids: electric constant ε, magnetic constant μ, gravitic constant γ, cogravitic constant η. For the solids, the constants ε and μ are well-determinable in the corresponding experiments that was mentioned at the beginning of this section. Concerning the constants γ and η, Li and Torr [13] in 1991 have presented Maxwell's equations for gravitation in a form, where the cogravitic constant η of a superconductor is different from the parameter η_0 for a vacuum. One year later, Li and Torr [14] have discussed the interrelationship between the magnetic and cogravitational fields in superconductors and estimated the value of the relative cogravitic constant η of a superconductor. In 1993, Torr and Li [15] have continued their analysis of gravitational effects in superconductors and studied some coupling between the gravitational and electric subsystems via superconductivity. In 2016, Füzfa [16] has studied weak interactions in solids between the electric or magnetic subsystem on one side and the gravitational or cogravitational subsystem on the other side. Therefore, it is necessary to state that the parameters ε, μ, γ, and η can be readily evaluated for various solids and naturally used for determination of the material parameters $\{\zeta, \xi, \beta, \lambda\}$. These last four parameters can be obtained with known values of the relative material parameters introduced in the following section. The third section provides some discussions.

2 The relative material parameters

In the transversely isotropic solid materials of symmetry class 6 *mm*, the velocity of the anti-plane polarized bulk acoustic wave can be calculated with the following expression [1]:

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

In definition (1), the material parameters C and ρ are listed in table 1. Also, the nondimensional parameter K_{emgc}^2 is called the coefficient of the electromagnetogravitocogravitomechanical coupling (CEMGCMC). This coefficient can be calculated with the following formulae [1, 17, 18, 19]:

$$K_{emgc}^2 = \frac{Z_1}{CZ_2} \tag{2}$$

where

$$Z_1 = e^2(\mu\gamma\eta + 2\beta\lambda\vartheta - \lambda^2\gamma - \beta^2\eta - \vartheta^2\mu) + h^2(\varepsilon\gamma\eta + 2\zeta\xi\vartheta - \vartheta^2\varepsilon - \zeta^2\eta - \xi^2\gamma) + g^2(\varepsilon\mu\eta + 2\alpha\xi\lambda - \lambda^2\varepsilon - \alpha^2\eta - \xi^2\mu) + f^2(\varepsilon\mu\gamma + 2\alpha\beta\zeta -$$

$$\beta^2\varepsilon - \alpha^2\gamma - \zeta^2\mu) + 2eh(\zeta\beta\eta + \xi\gamma\lambda + \vartheta^2\alpha - \alpha\gamma\eta - \zeta\lambda\vartheta - \xi\beta\vartheta) + 2eg(\alpha\beta\eta + \xi\vartheta\mu + \lambda^2\zeta - \alpha\lambda\vartheta - \zeta\mu\eta - \xi\beta\lambda) + 2ef(\alpha\gamma\lambda + \zeta\vartheta\mu + \beta^2\xi - \alpha\beta\vartheta - \zeta\beta\lambda - \xi\mu\gamma) + 2hg(\varepsilon\lambda\vartheta + \zeta\alpha\eta + \xi^2\beta - \alpha\xi\vartheta - \zeta\lambda\xi - \varepsilon\eta\beta) + 2hf(\varepsilon\beta\vartheta + \xi\alpha\gamma + \zeta^2\lambda - \alpha\zeta\vartheta - \zeta\xi\beta - \varepsilon\lambda\gamma) + 2gf(\varepsilon\beta\lambda + \xi\mu\zeta + \alpha^2\vartheta - \alpha\zeta\lambda - \alpha\beta\xi - \varepsilon\mu\vartheta) \quad (3)$$

$$Z_2 = (\varepsilon\mu - \alpha^2)(\gamma\eta - \vartheta^2) + (\beta\xi - \lambda\zeta)^2 - (\xi^2\mu\gamma + \beta^2\varepsilon\eta + \lambda^2\varepsilon\gamma + \zeta^2\mu\eta) + 2(\gamma\alpha\xi\lambda + \eta\alpha\beta\zeta + \varepsilon\beta\lambda\vartheta + \mu\zeta\xi\vartheta - \alpha\zeta\lambda\vartheta - \alpha\beta\xi\vartheta) \quad (4)$$

Table 1: The material parameters of the magnetoelectroelastic solid, their fundamental physical dimensions, and estimated values.

Material parameter, symbol	Dimension	Estimated values
Mass density, ρ	kg/m^3	10^3
Elastic stiffness constant, C	kg/(m×s^2)	10^9 to 10^{11}
Piezoelectric constant, e	kg$^{1/2}$/m$^{3/2}$	0.1 to 10
Piezomagnetic coefficient, h	kg$^{1/2}$/(m$^{1/2}$×s)	0.1 to 10^3
Piezogravitic constant, g	kg/m^2	10^5 to 10^{10}
Piezocogravitic coefficient, f	s^{-1}	10^{-16} to 10^{-8}
Electric constant, ε	s^2/m^2	10^{-10} to 10^{-8}
Magnetic constant, μ	-	10^{-6} to 10^{-3}
Electromagnetic constant, α	s/m	10^{-16} to 10^{-12}
Gravitic constant, γ	kg×s^2/m^3	10^{10} to 10^{11}
Cogravitic constant, η	m/kg	10^{-28} to 10^{-27}
Gravitocogravitic constant, ϑ	s/m	10^{-16} to 10^{-12}
Gravitoelectric constant, ζ	kg$^{1/2}$×s^2/m$^{5/2}$	10^{-8} to 10^{-2}
Cogravitoelectric constant, ξ	s/(kg$^{1/2}$×m$^{1/2}$)	10^{-45} to 10^{-40}
Gravitomagnetic constant, β	kg$^{1/2}$×s/m$^{3/2}$	10^{-6} to 10
Cogravitomagnetic constant, λ	m$^{1/2}$/kg$^{1/2}$	10^{-40} to 10^{-35}

All the material parameters present in (3) and (4) are listed in table 1. This form (4) can be naturally rewritten in the following forms [19]:

$$Z_2 = (\varepsilon\eta - \xi^2)(\mu\gamma - \beta^2) + (\alpha\vartheta - \lambda\zeta)^2 - (\vartheta^2\varepsilon\mu + \alpha^2\gamma\eta + \lambda^2\varepsilon\gamma + \zeta^2\mu\eta) + 2(\gamma\alpha\xi\lambda + \eta\alpha\beta\zeta + \varepsilon\beta\lambda\vartheta + \mu\zeta\xi\vartheta - \zeta\xi\beta\lambda - \alpha\beta\xi\vartheta) \quad (5)$$

$$Z_2 = (\varepsilon\gamma - \zeta^2)(\mu\eta - \lambda^2) + (\alpha\vartheta - \beta\xi)^2 - (\vartheta^2\varepsilon\mu + \alpha^2\gamma\eta + \xi^2\mu\gamma + \beta^2\varepsilon\eta) + 2(\gamma\alpha\xi\lambda + \eta\alpha\beta\zeta + \varepsilon\beta\lambda\vartheta + \mu\zeta\xi\vartheta - \zeta\xi\beta\lambda - \alpha\zeta\lambda\vartheta) \quad (6)$$

It is necessary to state that forms (4), (5), and (6) are equivalent. It is also necessary here to mention useful physical dimensions of some combinations of the material parameters. With table 1, one can find the following equalities: $[\rho/C] = [\varepsilon\mu] = [\gamma\eta] = [\alpha^2] = [\vartheta^2] = [\alpha\vartheta] = [\zeta\lambda] = [\xi\beta] = [s^2/m^2]$. These two parameters (1) and (2) are very important. Indeed, the speeds of both the new interfacial acoustic SH-wave [17] and the new dispersive acoustic SH-waves [18] in plates (thin films) actually depend on them. In equivalent forms (4), (5), and (6), the reader must focus on the first two terms on the right-hand side. It is clearly seen that in each equivalent form there are two first terms that consist of two cofactors. Using these two terms, it is possible to borrow the following inequalities from work [19]:

$$0 < \frac{\alpha^2\vartheta^2}{\varepsilon\mu\gamma\eta} < 1, 0 < \frac{\alpha^2}{\varepsilon\mu} < 1, 0 < \frac{\vartheta^2}{\gamma\eta} < 1 \quad (7)$$

$$0 < \frac{\xi^2\beta^2}{\varepsilon\mu\gamma\eta} < 1, 0 < \frac{\xi^2}{\varepsilon\eta} < 1, 0 < \frac{\beta^2}{\mu\gamma} < 1 \quad (8)$$

$$0 < \frac{\zeta^2\lambda^2}{\varepsilon\mu\gamma\eta} < 1, 0 < \frac{\zeta^2}{\varepsilon\gamma} < 1, 0 < \frac{\lambda^2}{\mu\eta} < 1 \quad (9)$$

Using inequalities (7), it is possible to write down the following relative magnetoelectric (ME) coefficients [20] listed in table 2:

$$\alpha_E = \frac{\partial E}{\partial H} = \frac{\alpha}{\varepsilon} \quad (10)$$

$$\alpha_H = \frac{\partial H}{\partial E} = \frac{\alpha}{\mu} \quad (11)$$

because it is convenient to deal with the following dimensionless parameter listed in table 2:

$$\alpha_E\alpha_H = \frac{\partial E}{\partial H}\frac{\partial H}{\partial E} = \frac{\alpha^2}{\varepsilon\mu} \quad (12)$$

Table 2: The relative material parameters α_E, α_H, ϑ_G, ϑ_F, ξ_E, ξ_F, β_H, β_G, ζ_E, ζ_G, λ_H, and λ_F, their fundamental physical dimensions, and estimated values.

Material parameter	Dimension	Estimated values
α_E	m/s	10^{-6} to 10^{-4}
α_H	s/m	10^{-10} to 10^{-8}
ϑ_G	$m^2/(kg \times s)$	10^{-26} to 10^{-22}
ϑ_F	$kg \times s/m^2$	10^{11} to 10^{15}
ζ_E	$kg^{1/2}/m^{1/2}$	10^{2} to 10^{6}
ζ_G	$m^{1/2}/kg^{1/2}$	10^{-18} to 10^{-12}
ξ_E	$m^{3/2}/(kg^{1/2} \times s)$	10^{-35} to 10^{-22}
ξ_F	$kg^{1/2} \times s/m^{3/2}$	10^{-17} to 10^{-13}
β_H	$kg^{1/2} \times s/m^{3/2}$	1 to 10^{4}
β_G	$m^{3/2}/(kg^{1/2} \times s)$	10^{-16} to 10^{-10}
λ_H	$m^{1/2}/kg^{1/2}$	10^{-34} to 10^{-32}
λ_F	$kg^{1/2}/m^{1/2}$	10^{-12} to 10^{-8}
$\alpha_E\alpha_H$, $\vartheta_G\vartheta_F$, $\beta_H\beta_G$, $\zeta_E\zeta_G$	-	$> 10^{-16}$
$\xi_E\xi_F$	-	$> 10^{-52}$
$\lambda_H\lambda_F$	-	$> 10^{-46}$
$\alpha_E\alpha_H\vartheta_G\vartheta_F$	-	$> 10^{-32}$
$\xi_E\xi_F\beta_H\beta_G$	-	$> 10^{-68}$
$\zeta_E\zeta_G\lambda_H\lambda_F$	-	$> 10^{-62}$

In (10) and (11) there are the partial first derivatives $\partial E/\partial H$ and $\partial H/\partial E$, respectively, where E and H stand for the electric and magnetic fields. Relative parameter α_E (10) is called the linear ME voltage coefficient that is the quantity generally measured during experiments [7, 21, 22]. The ME coefficients α_E (10) and α_H (11) are for the direct and converse ME effects [20]. The ME voltage coefficient α_E can be defined under the open electric circuit condition and expressed as $\alpha_E = \alpha/\varepsilon$, where ε is the effective permittivity (electric constant) for a solid. Similarly, the converse ME coefficient α_H (11) can be determined under the open magnetic circuit condition and expressed as follows: $\alpha_H = \alpha/\mu$, where μ is the effective permeability (magnetic constant). The ME coefficient α_H can be easily found in experiments similarly to the ME voltage coefficient. For instance, the dielectric constant $\varepsilon = 11.9\varepsilon_0$ for Cr_2O_3 [20] and therefore, the measured value of $\alpha = 2.67 \times 10^{-12}$ [s/m]. This means that the exchange speed $V_\alpha = 1/\alpha$ for monocrystal Cr_2O_3 is equal to $V_\alpha = 3.75 \times 10^{11}$ [m/s] > $C_L = 2.99782458 \times 10^8$ [m/s] and even $V_\alpha >> C_L$. With the effective permittivity ε and the effective permeability μ, the value of α can be measured for composites that can provide significantly stronger ME coupling. For composites, the effective parameters ε and μ can have very complicated forms [20].

Similar to the exchange between the electric and magnetic subsystems in the treated solids, an exchange between the gravitational and cogravitational subsystems can exist. Exploiting inequalities (7), it is therefore natural to introduce the following relative cogravitogravitic (CG) coefficients listed in table 2:

$$\vartheta_G = \frac{\partial G}{\partial F} = \frac{\vartheta}{\gamma} \tag{13}$$

$$\vartheta_F = \frac{\partial F}{\partial G} = \frac{\vartheta}{\eta} \tag{14}$$

Therefore there is the following dimensionless parameter:

$$\vartheta_G \vartheta_F = \frac{\partial G}{\partial F}\frac{\partial F}{\partial G} = \frac{\vartheta^2}{\gamma\eta} \tag{15}$$

In (13) and (14) there are the partial first derivatives $\partial G/\partial F$ and $\partial F/\partial G$, respectively, where G and F stand for the gravitational and cogravitational fields. Expressions (13) and (14) for the direct and converse CG effects can be used for experimental measurements of the gravitocogravitic constant ϑ for both monocrystals and composites. For composites however, the forms for the effective gravitic constant γ and the effective cogravitic constant η can be found for an individual composite and can be very complicated.

Similarly, it is possible now to utilize inequalities (8). So, it is also natural to introduce the following relative cogravitoelectric (CE) coefficients that are listed in table 2:

$$\xi_E = \frac{\partial E}{\partial F} = \frac{\xi}{\varepsilon} \tag{16}$$

$$\xi_F = \frac{\partial F}{\partial E} = \frac{\xi}{\eta} \tag{17}$$

As a result, the following expression can be written:

$$\xi_E \xi_F = \frac{\partial E}{\partial F}\frac{\partial F}{\partial E} = \frac{\xi^2}{\varepsilon\eta} \tag{18}$$

Using inequalities (8), it is also possible to introduce the following relative gravitomagnetic (GM) coefficients listed in table 2:

$$\beta_H = \frac{\partial H}{\partial G} = \frac{\beta}{\mu} \tag{19}$$

$$\beta_G = \frac{\partial G}{\partial H} = \frac{\beta}{\gamma} \tag{20}$$

Coefficients (19) and (20) as the cofactors represent the following dimensionless form present in inequalities (8):

$$\beta_H \beta_G = \frac{\partial H}{\partial G}\frac{\partial G}{\partial H} = \frac{\beta^2}{\mu\gamma} \tag{21}$$

Finally, it is possible to employ inequalities (9). Therefore, to introduce the following relative gravitoelectric (GE) coefficients listed in table 2 is natural:

$$\zeta_E = \frac{\partial E}{\partial G} = \frac{\zeta}{\varepsilon} \tag{22}$$

$$\zeta_G = \frac{\partial G}{\partial E} = \frac{\zeta}{\gamma} \tag{23}$$

These coefficients produce the following form present in inequalities (9):

$$\zeta_E \zeta_G = \frac{\partial E}{\partial G}\frac{\partial G}{\partial E} = \frac{\zeta^2}{\varepsilon\gamma} \tag{24}$$

With inequalities (9), it is natural to introduce the following relative cogravitomagnetic (CM) coefficients listed in table 2:

$$\lambda_H = \frac{\partial H}{\partial F} = \frac{\lambda}{\mu} \tag{25}$$

$$\lambda_F = \frac{\partial F}{\partial H} = \frac{\lambda}{\eta} \tag{26}$$

These relative cogravitomagnetic coefficients provide the following form in inequalities (9):

$$\lambda_H \lambda_F = \frac{\partial H}{\partial F}\frac{\partial F}{\partial H} = \frac{\lambda^2}{\mu\eta} \tag{27}$$

3 Discussion

The physical dimensions of all the relative material parameters are listed in table 2. It is expected that all of them can be measured for both monocrystals and composite materials. However, the experimental determination of the introduced material parameters requires creation of proper experimental tools. So, a lot of experimental setups must be combined in order to measure all the material parameters of the smart magnetoelectric materials incorporating the gravitational phenomena. This is suitable for a large research organization. All the material parameters for the treated case, namely $\{\rho, C, e, h, g, f, \varepsilon, \mu, \gamma, \eta, \alpha, \vartheta, \zeta, \lambda, \xi, \beta\}$ listed in table 1 are necessary to calculate propagation speeds of various acoustic waves. It is expected that one, two, or several parameters of $\{\alpha, \vartheta, \zeta, \lambda, \xi, \beta\}$ can be crucial for the existence of some (surface) acoustic waves. It is also expected that the experimental determination of the relative parameters $\{\vartheta_G, \vartheta_F, \xi_E, \xi_F, \beta_H, \beta_G, \zeta_E, \zeta_G, \lambda_H, \lambda_F\}$ listed in table 2 is preferable because there are successful measurements of relative magnetoelectric coefficients (10) and (11) [20] during the last several decades. Indeed, Astrov [23] has experimentally determined the electromagnetic constant α for the monocrystal Cr_2O_3 in 1960. However, many composite materials show significantly stronger ME interactions. This allows the manufacture of various magnetoelectric technical devices such as the wireless powering systems [24, 25], energy harvesting [26], tunable inductors [27], magnetic-field sensors [28-35], gyrators and transformers [36, 37], dual electric-field- and magnetic-field-tunable microwave and millimeter-wave devices [38-42], and miniature antennas [43-46]. It is expected that using suitable monocrystals or created composites with the electric, magnetic, gravitational, and cogravitational effects, it also is possible to constitute, for instance, gravitational-field and cogravitational-field sensors, etc. It is also natural to utilize them for the energy harvesting instead of the conventional piezoelectrics [47-50].

Concerning the infrastructure development for the instant interplanetary communication, some schemes were discussed in paper [51]. It is assumed that planetary colonists between each other can have conventional L-communication at the speed of light on the guest planet. However, the Λ-communication must be used when there is a necessity to communicate with the home planet because the Λ-communication based on the new fast waves propagating at the speeds $\Lambda_{01} = (\zeta_0\lambda_0)^{-1/2} \rightarrow 10^{13}C_L$ and $\Lambda_{02} = (\xi_0\beta_0)^{-1/2} \rightarrow 10^{13}C_L$ can already provide the instant interplanetary communication. This can be useful for the remote health monitoring of the planetary colonists. For this new communication era based on the symbiosis of the electromagnetic and gravitational phenomena, the parameters $\{\varepsilon_0, \mu_0, \gamma_0, \eta_0, \alpha_0, \vartheta_0, \zeta_0, \lambda_0, \xi_0, \beta_0\}$ for a vacuum must be also known. Today, only the values of the parameters $\{\varepsilon_0, \mu_0, \gamma_0, \eta_0\}$ for a vacuum are well-known. Therefore, the rest parameters $\{\alpha_0, \vartheta_0, \zeta_0, \lambda_0, \xi_0, \beta_0\}$ representing the exchange constants must be also determined in proper experiments. It is expected that these parameters for a vacuum can be determined when the experimental techniques will be successfully developed for measurements of the material parameters for the solids. According to the evaluations done in table 2, the values of $\alpha_E\alpha_H$, $\vartheta_G\vartheta_F$, $\beta_H\beta_G$, and $\zeta_E\zeta_G$ are larger than 10^{-16}. Therefore there are possibilities to properly measure the values of the relative parameters ϑ_G, ϑ_F, β_H, β_G, ζ_E, and ζ_G because the values of α_E and α_H are precisely measured for the last several decades. For the proper measurements of the rest parameters ξ_E, ξ_F, λ_H, and λ_F ($\xi_E\xi_F > 10^{-52}$ and $\lambda_H\lambda_F > 10^{-46}$ in table 2) it is expected that more sensitive experimental tools must be created.

4 Conclusion

Incorporating gravitational phenomena for the magnetoelectroelastic materials, this report has introduced the relative material parameters ϑ_G, ϑ_F, ξ_E, ξ_F, β_H, β_G, ζ_E, ζ_G, λ_H, and λ_F defined by formulas (13)-(27) and listed in table 2. These parameters are natural implement to the well-known relative material parameters α_E and α_M that are successfully measured during the last several decades. Experimental determinations of all the aforementioned relative material parameters lead to the utilization of the complete set of the material parameters

$\{\rho, C, e, h, g, f, \varepsilon, \mu, \gamma, \eta, \alpha, \vartheta, \zeta, \lambda, \xi, \beta\}$ listed in table 1. The complete set of the material parameters will allow for the researchers and engineers to study the acoustic wave propagation in the (composite) solids. Also, this will actually contribute to the development of the instant interplanetary communication based on the new fast waves propagating in both the solids and a vacuum at the speeds thirteen orders faster than the speed of light in a vacuum. So, it is possible to state that this work has touched some gravitational engineering research arenas for new communication era based on gravitational phenomena.

References

[1] A.A. Zakharenko, On piezogravitocogravitoelectromagnetic shear-horizontal acoustic waves. Canadian Journal of Pure and Applied Sciences, 10 (3) (2016), 4011-4028; DOI: https://doi.org/10.5281/zenodo.1301184.

[2] A.A. Zakharenko, The problem of finding of eigenvectors for 4P-SH-SAW propagation in 6 *mm* media. Canadian Journal of Pure and Applied Sciences, 11 (1) (2017), 4103-4119; DOI: https://doi.org/10.5281/zenodo.1301202.

[3] B.P. Abbott, R. Abbott, T.D. Abbott, M.R. Abernathy, F. Acernese, K. Ackley, C. Adams, T. Adams, P. Addesso, R.X. Adhikari *et al.*, Observation of gravitational waves from a binary black hole merger. Physical Review Letters, 116 (6) (2016), 061102, 16 pages.

[4] B.M. Yavorsky, A.A. Detlaf and A.K. Lebedev, *The Physics Reference Book for Engineers and Student of the Higher Education*, 8th edition, ONICS Publishers, Moscow, Russia (2006), 1054 pages.

[5] A.A. Blistanov, V.S. Bondarenko, N.V. Perelomova, F.N. Strizhevskaya, V.V. Chkalova and M.P. Shaskol'skaya, Acoustical Crystals, in: M.P. Shaskol'skaya (Ed.), *Acoustical Crystals*, Nauka, Moscow, Russia (1982), 632 pages (in Russian).

[6] F. Fiorillo, Measurements of magnetic materials. Metrologia, 47 (2) (2010), S114-S142; DOI: https://doi.org/10.1088/0026-1394/47/2/S11.

[7] Ü. Özgür, Ya. Alivov and H. Morkoç, Microwave ferrites, part 2: Passive components and electrical tuning. Journal of Materials Science: Materials in Electronics, 20 (10) (2009), 911-952.

[8] M. Fiebig, Revival of the magnetoelectric effect. Journal of Physics D: Applied Physics, 38 (8) (2005), R123-R152.

[9] T. Kimura, Magnetoelectric hexaferrites. Annual Review of Condensed Matter Physics, 3 (1) (2012), 93-110.

[10] A. Einstein, Die Grundlage der allgemeinen Relativitätstheorie. Annalen der Physik, 354 (7) (1916), 769-822. Version of Record online: 14 MAR 2006, DOI: https://doi.org/10.1002/andp.19163540702.

[11] O. Heaviside, A gravitational and electromagnetic analogy. The Electrician, 31 (Part I) (1893), 281-282 and 359.

[12] O.D. Jefimenko, *Gravitation and Cogravitation. Developing Newton's Theory of Gravitation to its Physical and Mathematical Conclusion*, Electret Scientific Publishing, USA (2006), 367 pages.

[13] N. Li and D.G. Torr, Effects of a gravitomagnetic field on pure superconductors. Physical Review D, 43 (2) (1991), 457-459.

[14] N. Li and D.G. Torr, Gravitational effects on the magnetic attenuation of superconductors. Physical Review B, 64 (9) (1992), 5489-5495.

[15] D.G. Torr and N. Li, Gravitoelectric-electric coupling via superconductivity. Foundations of Physics Letters, 6 (4) (1993), 371-383.

[16] A. Füzfa, How current loops and solenoids curve space-time. Physical Review D, 93 (2) (2016), 024014.

[17] A.A. Zakharenko, On new interfacial four potential acoustic SH-wave in dissimilar media pertaining to transversely isotropic class 6 *mm*. Canadian Journal of Pure and Applied Sciences, 11 (3) (2017), 4321-4328; DOI: https://doi.org/10.5281/zenodo.1301215.

[18] A.A. Zakharenko, On existence of new dispersive four-potential SH-waves in 6 *mm* plates for new communication era based on gravitational phenomena. Canadian Journal of Pure and Applied Sciences, 12 (3) (2018), 4585-4591; DOI: http://doi.org/10.5281/zenodo.1471100.

[19] A.A. Zakharenko, On separation of exchange terms for four-potential acoustic SH-wave case with dependence on gravitational parameters. Hadronic Journal, 41 (4) (2018), 349-370; http://doi.org/10.5281/zenodo.2842082.

[20] M.I. Bichurin, V.M. Petrov, R.V. Petrov and A.S. Tatarenko, *Magnetoelectric Composites*, Jenny Stanford Publishing, New York, USA (2019), 296 pages. DOI: https://doi.org/10.1201/9780429488672.

[21] M.I. Bichurin, I.A. Kornev, V.M. Petrov, A.S. Tatarenko, Yu.V. Kiliba and G. Srinivasan, Theory of magnetoelectric effects at microwave frequencies in a piezoelectric/magnetostrictive multilayer composite. Physical Review B, 64 (9) (2001), 094409.

[22] J.-P. Rivera, A short review of the magnetoelectric effect and related experimental techniques on single phase (multi-) ferroics. The European Physical Journal B, 71 (3) (2009), 299-313.

[23] D.N. Astrov, The magnetoelectric effect in antiferromagnets. Soviet Physics – Journal of Experimental and Theoretical Physics (JETP), 11 (1960), 708-709 [Zhurnal Experientalnoi i Teoreticheskoi Fiziki (USSR), 38 (3) (1960), 984-985].

[24] A. Bayrashev, W.P. Robbins and B. Ziaie, Low frequency wireless powering of microsystems using piezoelectric–magnetostrictive laminate composites. Sensors and Actuators A: Physical, 114 (2-3) (2004), 244-249.

[25] L. Bian, Y. Wen, P. Li, Q. Gao and M. Zheng, Magnetoelectric transducer with high quality factor for wireless power receiving. Sensors and Actuators A: Physical, 150 (2) (2009), 207-211.

[26] S. Dong, J. Zhai, J.F. Li, D. Viehland and S. Priya, Multimodal system for harvesting magnetic mechanical energy. Applied Physics Letters, 93 (10) (2008), 103511; DOI: http://dx.doi.org/10.1063/1.2982099.

[27] J. Lou, D. Reed, M. Liu and N.X. Sun, Electrostatically tunable magnetoelectric inductors with large inductance tunability. Applied Physics Letters, 94 (11) (2009), 112508; DOI: https://doi.org/10.1063/1.3103273.

[28] J. Zhai, Z. Xing, S. Dong, J.F. Li and D. Viehland, Detection of pico-Tesla magnetic field using magneto-electric sensors at room temperature. Applied Physics Letters, 88 (6) (2006), 062510; DOI: https://doi.org/10.1063/1.2172706.

[29] J. Zhai, S. Dong, Z. Xing, J.F. Li and D. Viehland, Geomagnetic sensor based on giant magnetoelectric effect. Applied Physics Letters, 91 (12) (2007), 123513; DOI: https://doi.org/10.1063/1.2789391.

[30] Z.P. Xing, J.Y. Zhai, S.X. Dong, J.F. Li, D. Viehland and W.G. Odendaal, Modeling and detection of quasi-static nanotesla magnetic field variations using magnetoelectric laminate sensors. Measurement Science and Technology, 19 (1) (2008), 015206; DOI: https://doi.org/10.1088/0957-0233/19/1/015206.

[31] Y.K. Fetisov, A.A. Bush, K.E. Kamentsev, A.Y. Ostashchenko and G. Srinivasan, Ferrite-piezoelectric multilayers for magnetic field sensors. The IEEE Sensors Journal, 6 (4) (2006), 935-938; DOI: https://doi.org/10.1109/JSEN.2006.877989.

[32] R. Bergs, R.A. Islam, M. Vickers, H. Stephanou and S. Priya, Magnetic field anomaly detector using magnetoelectric composites. Journal of Applied Physics, 101 (2) (2007), 024108; DOI: https://doi.org/10.1063/1.2427095.

[33] C. Israel, N.D. Mathur and J.F. Scott, A one-cent room-temperature magnetoelectric sensor. Nature Materials, 7 (2) (2008), 93-94; DOI: https://doi.org/10.1038/nmat2106.

[34] M. Vopsaroiu, J. Blackburn and M.G. Cain, A new magnetic recording read head technology based on the magneto-electric effect. Journal of Physics D: Applied Physics, 40 (17) (2007), 5027-5033; DOI: https://doi.org/10.1088/0022-3727/40/17/003.

[35] P. Zhao, Z. Zhao, D. Hunter, R. Suchoski, C. Gao, S. Mathews, M. Wuttig and I. Takeuchi, Fabrication and characterization of all-thin-film magnetoelectric sensors. Applied Physics Letters, 94 (24) (2009), 243507; DOI: https://doi.org/10.1063/1.3157281.

[36] S. Dong, J.F. Li and D. Viehland, Voltage gain effect in a ring-type magnetoelectric laminate. Applied Physics Letters, 84 (21) (2004), 4188-4190; DOI: https://doi.org/10.1063/1.1756676.

[37] J. Zhai, J.F. Li, S. Dong, D. Viehland and M.I. Bichurin, A quasi (unidirectional) Tellegen gyrator. Journal of Applied Physics, 100 (12) (2006), 124509; DOI: https://doi.org/10.1063/1.2402967.

[38] Y.K. Fetisov and G. Srinivasan, Ferrite/piezoelectric microwave phase shifter: studies on electric field tunability. Electronics Letters, 41 (19) (2005), 1066-1067; DOI: https://doi.org/10.1049/el:20051653.

[39] G. Srinivasan, I.V. Zavislyak and A.S. Tatarenko, Millimeter-wave magnetoelectric effects in bilayers of barium hexaferrite and lead zirconate titanate. Applied Physics Letters, 89 (15) (2006), 152508; DOI: https://doi.org/10.1063/1.2360901.

[40] A.S. Tatarenko, V. Gheevarughese and G. Srinivasan, Magnetoelectric microwave band-pass filter. Electronics Letters, 42 (9) (2006), 540-541; DOI: https://doi.org/10.1049/el:20060167.

[41] A.B. Ustinov, G. Srinivasan and B.A. Kalinikos, Ferrite-ferroelectric hybrid wave phase shifters. Applied Physics Letters, 90 (3) (2007), 031913; DOI: https://doi.org/10.1063/1.2432953.

[42] J. Das, B.A. Kalinikos, A.R. Barman and C.E. Patton, Multifunctional dual-tunable low loss ferrite-ferroelectric heterostructures for microwave devices. Applied Physics Letters, 91 (17) (2007), 172516; DOI: https://doi.org/10.1063/1.2802577.

[43] R.V. Petrov, A.S. Tatarenko, S. Pandey, G. Srinivasan, J.V. Mantese and R. Azadegan, Miniature antenna based on magnetoelectric composites.

Electronics Letters, 44 (8) (2008), 506-507; DOI: https://doi.org/10.1049/el:20080325.

[44] N.X. Sun, J.W. Wang, A. Daigle, C. Pettiford, H. Mosallaei and C. Vittoria, Electronically tunable magnetic patch antennas with metal magnetic films. Electronics Letters, 43 (8) (2007), 434-435; DOI: https://doi.org/10.1049/el:20070560.

[45] C.C.M. Wu, M. Kahn and W. Moy, Piezoelectric ceramics with functional gradients: a new application in material design. Journal of the American Ceramic Society, 79 (3) (1996), 809-812; DOI: https://doi.org/10.1111/j.1151-2916.1996.tb07951.x.

[46] G.-M. Yang, X. Xing, A. Daigle, M. Liu, O. Obi, S. Stoute, K. Naishadham and N.X. Sun, Tunable miniaturized patch antennas with self-biased multilayer magnetic films. The IEEE Transactions on Antennas and Propagation, 57 (7) (2009), 2190-2193; DOI: https://doi.org/10.1109/TAP.2009.2021972.

[47] P.K. Sharma and P.V. Baredar, Analysis on piezoelectric energy harvesting small scale device – a review. Journal of King Saud University - Science (Production and hosting by Elsevier B.V.), 31 (4) (2019), 869-877; DOI: https://doi.org/10.1016/j.jksus.2017.11.002.

[48] J. Iannacci, Microsystem based Energy Harvesting (EH-MEMS): Powering pervasivity of the Internet of Things (IoT) – A review with focus on mechanical vibrations. Journal of King Saud University - Science (Production and hosting by Elsevier B.V.), 31 (1) (2019), 66-74; DOI: http://doi.org/10.1016/j.jksus.2017.05.019.

[49] A. Nechibvute, A. Chawanda and P. Luhanga, Piezoelectric energy harvesting devices: An alternative energy source for wireless sensors. Smart Materials Research (Hindawi Publishing Corporation), 2012 (2012), 853481, 13 pages; DOI: http://dx.doi.org/10.1155/2012/853481.

[50] Sh. Priya, H.-Ch. Song, Yu. Zhou, R. Varghese, A. Chopra, S.-G. Kim, I. Kanno, L. Wu, D.S. Ha, J. Ryu and R.G. Polcawich, A review on piezoelectric energy harvesting: Materials, methods, and circuits. Energy Harvesting and Systems, 4 (1) (2017), 3-39; DOI: http://doi.org/10.1515/ehs-2016-0028.

[51] A.A. Zakharenko, On necessity of development of instant interplanetary telecommunication based on some gravitational phenomena for remote medical diagnostics and treatment. Canadian Journal of Pure and Applied Sciences, 12 (2) (2018), 4481-4487; DOI: https://doi.org/10.5281/zenodo.1301289.