*Research*

# Maxwell-Heaviside Description of Curvature Waves: A Second Generation Model

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**Abstract:**
A model is presented to describe curvature waves in analogy with derivation of light waves in free space. Starting from Maxwell-Heaviside equations, the differential wave equations for electric and magnetic fields are derived, and their solution, i.e. sinusoidal depedence on space and time at precisely defined speed - determined by the permittivity and permeability of free space - is given. This formalism is then applied to the gravitational and kinetic fields subjected to the curvature of space. Massive bodies are described as curvature lumps - regions with given average space curvature distinguished from the background space curvature. Companion kinetic field is represented by the deviation of the angular frequency of the curvature lump from the baseline. The identity of the companion field was indicated from dimensional analysis.

**Keywords:** Gravitation; Curvature; Gravitational waves; Curvature waves; Speed of gravitational waves; Maxwell equations; Heaviside

# 1 Introduction

Following empirical investigations, gravitational, electromagnetic, the weak and strong nuclear interactions were outlined as fundamental physical interactions. In line with the assumption that physical laws are universal, a common origin of these interactions is being sought theoretically and experimentally, but an unified interaction theory has not yet been acknowledged (Weinberg, 1980). While experiments involving electromagnetic fields are accessible within the macroscopic scale, gravitational and nuclear interactions present challenges as regards experiments. The theory of general relativity indicates that gravitational interaction is connected to the curvature of space (Einstein, 1916). Following this idea, the analogy with derivation of the light waves from Maxwell-Heaviside equations (Heaviside, 1894) and the first generation model of gravitation described in (Kralj-Iglič, 2025), here we derive the equations describing the waves of the gravitational and kinetic fields. The velocity of the waves turns out to depend on two constants, the gravitational permittivity of space $\varepsilon_G$ and the kinetic permeability of space $\mu_K$. First we present the formalism with which the light waves are derived from the Maxwell-Heaviside equations and then we use this formalism for derivation of the "gravitokinetic" waves.

# 2 Maxwell - Heaviside model of electromagnetism

James Clark Maxwell constructed his theory based on the vector potential of the magnetic field $\mathbf{A}$ and scalar potential of the electric field $\psi$ (Hunt, 2012). Oliver Heaviside re-expressed the Maxwell's theory in a more concise form based directly on the electric field $\mathbf{E}$ and magnetic field $\mathbf{H}$ (Heaviside, 1894; Hunt, 2012). Heaviside then used his energy-flow theorem and derived what he called the "second circuital law," which related the curl of $\mathbf{E}$ directly to the time derivative of a "fitting partner" in the Maxwell's first circuital law ($\mathbf{H}$), and the curl of $\mathbf{H}$ to $\mathbf{E}$ and its time derivative (Hunt, 2012). By combining these expressions with Maxwell's expressions for the divergence of the electric displacement $\mathbf{D}$ and the magnetic induction $\mathbf{B}$, Heaviside arrived at the compact set of four differential vector relations that are now known as Maxwell's equations. Heaviside published the energy-flow theorem and built his model of electromagnetism in a series of papers (Hunt, 2012). As the form of the equations was of importance to us, by nominating them as the Maxwell-Heaviside equations we indicate the Heaviside's important contribution to the simplicity and clarity of the formulation.

# 3 Theory

## 3.1 Description of light by electric and magnetic field

We take that the source of the field $\mathbf{D}$ is charge $q$,

$$\nabla \cdot \mathbf{D} = \varrho_{\mathrm{el}}, \tag{1}$$

where

$$\rho_{\mathrm{el}} = \frac{\mathrm{d}q}{\mathrm{d}V}, \tag{2}$$

and $V$ is the volume. For convenience of scaling, we introduce a constant $\varepsilon_0$ and a field $\mathbf{E}$ so that

$$\mathbf{D} = \varepsilon_0 \mathbf{E}. \tag{3}$$

Proportionality constant $\varepsilon_0 = 8.9 \times 10^{-12}$ As/Vm is called the permittivity of free space. The magnetic field **B** has no monopole sources

$$\nabla \cdot \mathbf{B} = \mathbf{0} \tag{4}$$

with proportional field **H**

$$\mathbf{B} = \mu_{\mathbf{0}} \mathbf{H} \tag{5}$$

where $\mu_0 = 4\pi \times 10^{-7}$ Vm/As is called permeability of free space.

The vortex equations are

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial \mathbf{t}}. \tag{6}$$

and

$$\nabla \times \mathbf{H} = \mathbf{j_{el}} + \frac{\partial \mathbf{D}}{\partial \mathbf{t}}, \tag{7}$$

where

$$\mathbf{j}_{\text{el}} = \frac{\mathrm{d}}{\mathrm{d}S} \left( \frac{\mathrm{d}q}{\mathrm{d}t} \right) \mathbf{I}_{\text{el}} \tag{8}$$

is the density of mass current, $S$ is the cross section area and $\mathbf{I}_{\text{el}}$ is the unit vector in the direction of the current. The movement in straight lines can be included in considering rotation with respect to limiting small curvature.

Consider there are no charges and therefore no current so that

$$\nabla \cdot \mathbf{D} = 0. \tag{9}$$

and

$$\mathbf{j}_{\text{el}} = 0. \tag{10}$$

Applying a double vector product with vector nabla on the vortex equations, we obtain

$$\nabla \times \nabla \times \mathbf{H} = \nabla \times (-\frac{\partial \mathbf{D}}{\partial t}). \tag{11}$$

and

$$\nabla \times \nabla \times \mathbf{E} = \nabla \times (\frac{\partial \mathbf{B}}{\partial t}). \tag{12}$$

The double vector product of some vector **X** reads

$$\nabla \times \nabla \times \mathbf{X} = \nabla(\nabla \cdot \mathbf{X}) - \nabla^{\mathbf{2}} \mathbf{X} \tag{13}$$

so that with Eqs.(**??**) and (10)

$$\nabla \times \nabla \times \mathbf{H} = -\nabla^2 \mathbf{H}, \tag{14}$$

and

$$\nabla \times \nabla \times \mathbf{E} = -\nabla^2 \mathbf{E}. \tag{15}$$

Combining Eqs.(36) and (40), and (12) and (15) yields

$$-\nabla^2 \mathbf{H} = \nabla \times (-\frac{\partial \mathbf{D}}{\partial t}), \tag{16}$$

$$-\nabla^2 \mathbf{E} = \nabla \times (-\frac{\partial \mathbf{B}}{\partial t}). \tag{17}$$

Changing the consecutive order of operations in the right hand side of Eq.(18) and (29), and Eq.(42) and (29) yields

$$\nabla^2 \mathbf{H} = (\frac{\partial(\nabla \times \mathbf{D})}{\partial t}), \tag{18}$$

$$\nabla^2\mathbf{E} = (\frac{\partial(\nabla\times\mathbf{B})}{\partial t}). \tag{19}$$

Considering Eqs.(6) and (7), we get

$$\nabla^2\mathbf{H} = \varepsilon_0\mu_0\frac{\partial^2\mathbf{H}}{\partial t^2} \tag{20}$$

and

$$\nabla^2\mathbf{E} = \varepsilon_0\mu_0\frac{\partial^2\mathbf{E}}{\partial t^2} \tag{21}$$

with periodic solutions with respect to time and space

$$\mathbf{E} = \mathbf{E_0}\sin(\mathbf{k}\cdot\mathbf{r} - \omega\mathbf{t}) \tag{22}$$

and

$$\mathbf{H} = \mathbf{H_0}\sin(\mathbf{k}\cdot\mathbf{r} - \omega\mathbf{t} + \delta) \tag{23}$$

where $\mathbf{k}$ is the wave vector, $\mathbf{r}$ is the displacement, $\delta$ is the phase lag and $\omega$ is the angular frequency of the waves.

The velocity of the light waves $c$ is given by

$$c = \sqrt{\frac{1}{\varepsilon_0\mu_0}} = 3\times10^8\text{m/s}. \tag{24}$$

## 3.2 Description of gravito-kinetic waves

Assuming that the space is isotropic, we take that the source of the field $\mathbf{G_C}$ is a lump of the space curvature,

$$\nabla\cdot(\mathbf{G}_C - \mathbf{G}_{C,0}) = \langle H\rangle, \tag{25}$$

where $H$ is the mean curvature of the space

$$H = \frac{1}{2}(C_1 + C_2), \tag{26}$$

$C_1$ and $C_2$ are the two principal curvatures and $\mathbf{G}_{C,0}$ is the baseline curvature of the space. For convenience of scaling, we introduce a constant $\varepsilon_G$ and, analogously with Maxwellian notation, call it gravitational permittivity of the space (Nyambuya, 2015)

$$\mathbf{G}_C = \varepsilon_G\mathbf{g}. \tag{27}$$

We introduce companion kinetic fields $\mathbf{K}$,

$$\nabla\cdot(\mathbf{K} - \mathbf{K}_0) = 0 \tag{28}$$

and $\kappa$

$$\mathbf{K} = \mu_{\mathbf{K}}\kappa \tag{29}$$

where $\mu_K$ is a proportionality parameter coupling the kinetic fields that we call kinetic permeability of the space and $\mathbf{K}_0$ is the baseline kinetic field.

The vortex equations are

$$\nabla\times(\mathbf{g} - \mathbf{g}_0) = -\frac{\partial(\mathbf{K} - \mathbf{K}_0)}{\partial t}. \tag{30}$$

and

$$\nabla\times(\kappa - \kappa_{\mathbf{0}}) = \mathbf{j}_C + \frac{\partial(\mathbf{G}_C - \mathbf{G}_{C,0})}{\partial t}, \tag{31}$$

where $\mathbf{j}$ is the density of the current of curvature lumps

$$\mathbf{j}_C = \frac{\mathrm{d}}{\mathrm{d}S} \left( \frac{\mathrm{d}\langle C \rangle}{\mathrm{d}t} \right) \mathbf{I}_C, \tag{32}$$

$\mathrm{d}S$ is cross section element, $t$ is time and $\mathbf{I}_C$ is the unit vector in the direction of the current. Subtraction of the baseline parameters $\mathbf{G}_{C,0}$ and $\mathbf{K_0}$ denotes that the expected undulations will be about these values.

Consider that there are no curvature lumps and therefore

$$\nabla \cdot (\mathbf{G}_C - \mathbf{G}_{C,0}) = 0 \tag{33}$$

and

$$\mathbf{j} = 0. \tag{34}$$

Applying a double vector product with vector nabla, we obtain from Eq.(30),

$$\nabla \times \nabla \times (\mathbf{g} - \mathbf{g}_0) = \nabla \times \left( -\frac{\partial(\mathbf{K} - \mathbf{K}_0)}{\partial t} \right). \tag{35}$$

and

$$\nabla \times \nabla \times (\kappa - \kappa_0) = \nabla \times \left( -\frac{\partial(\mathbf{G}_C - \mathbf{G}_{C,0}}{\partial t} \right). \tag{36}$$

The double vector product reads,

$$\nabla \times \nabla \times (\mathbf{g} - \mathbf{g_0}) = \nabla(\nabla \cdot (\mathbf{g} - \mathbf{g}_0)) - \nabla^2(\mathbf{g} - \mathbf{g_0}) \tag{37}$$

and

$$\nabla \times \nabla \times (\kappa - \kappa_{\mathbf{0}}) = \nabla(\nabla \cdot (\kappa - \kappa_0)) - \nabla^2(\kappa - \kappa_0) \tag{38}$$

and so that with Eqs.(33) and (28)

$$\nabla \times \nabla \times (\mathbf{g} - \mathbf{g}_0) = -\nabla^2(\mathbf{g} - \mathbf{g}_0) \tag{39}$$

and

$$\nabla \times \nabla \times (\kappa - \kappa_0) = -\nabla^2(\kappa - \kappa_0) \tag{40}$$

Combining Eqs.(35) and (39), and Eqs.(36) and (40), respectively, yields

$$-\nabla^2(\mathbf{g} - \mathbf{g}_0) = \nabla \times (-\frac{\partial(\mathbf{K} - \mathbf{K}_0)}{\partial t}). \tag{41}$$

and

$$-\nabla^2(\kappa - \kappa_0) = \nabla \times (-\frac{\partial(\mathbf{G_C} - \mathbf{G_{C,0}})}{\partial t}). \tag{42}$$

Changing the consecutive order of operations in the right hand sides of Eqs.(41) and (42), and considering Eqs.(27) and (29), and Eqs.(30) and (31) yields

$$\nabla^2(\mathbf{g} - \mathbf{g}_0) = \varepsilon_G \mu_K \frac{\partial^2(\mathbf{g} - \mathbf{g}_0)}{\partial t^2} \tag{43}$$

and

$$\nabla^2(\kappa - \kappa_0) = \varepsilon_G \mu_K \frac{\partial^2(\kappa - \kappa_0)}{\partial t^2} \tag{44}$$

with periodic solutions in dependence of time and space

$$\mathbf{g} = \mathbf{g}_0 + \Delta\mathbf{g} \sin(\mathbf{k_G} \cdot \mathbf{r} - \omega t) \tag{45}$$

and

$$\kappa = \kappa_{\mathbf{0}} + \mathbf{\Delta}\kappa \sin(\mathbf{k_G} \cdot \mathbf{r} - \omega \mathbf{t} + \delta) \tag{46}$$

where $\Delta\mathbf{g}$ and $\Delta\kappa$ are the amplitudes, $\mathbf{k_G}$ is the wave vector, $\mathbf{r}$ is the displacement, $\delta$ is the phase lag and $\omega$ is the angular frequency of the waves. The velocity of the waves $c_G$ is given by

$$c_G = \sqrt{\frac{1}{\varepsilon_G \mu_K}}. \tag{47}$$

# 4 Estimation of fields and constants

We made dimensional analysis of the model. The dimension of the curvature is 1/m. It follows from Eq.(25) that the field $\mathbf{G}$ is dimensionless. Further, it follows from Eq.(31) that the dimension of $\kappa$ is m/s. We take that the kinetic field is angular frequency

$$\mathbf{K} = \Omega \tag{48}$$

with dimension 1/s. It follows from Eq.(30) that the dimension of $\mathbf{g}$ is m/s$^2$ representing gravitational acceleration. Using Eqs.(27) and (29) yields also the dimensions of the proportionality constants $\varepsilon_G$ (s$^2$/m) and $\mu_K$ (1/m), respectively. The dimensions of the fields and constants are concisely given in Table 1. It can be verified by using Eq.(47) that the velocity of gravitational waves has the correct dimension m/s. It can be noted that the dimension of the mass (kg) is not involved in the model.

Table 1. Dimensions of the fields and constants.

| Quantity | Dimension |
|---|---|
| $\mathbf{G}$ | |
| $\mathbf{g}$ | m/s$^2$ |
| $\mathbf{K} = \Omega$ | 1/s |
| $\kappa$ | m/s |
| $\varepsilon_G$ | s$^2$/m |
| $\mu_K$ | 1/m |

To estimate the constant $\varepsilon_G$ we consider the definition of gravitational field by the mass (Nyanbuya, 2015; Kralj-Iglič, 2025),

$$\nabla \cdot \mathbf{G} = \rho, \tag{49}$$

where

$$\rho = \frac{\mathrm{d}m}{\mathrm{d}V}, \tag{50}$$

$m$ is mass and $V$ is volume. The companion field was introduced as (Kralj-Iglič, 2025)

$$\mathbf{G} = \gamma \mathbf{\Gamma} \tag{51}$$

with

$$\gamma = \frac{1}{4\pi G}, \tag{52}$$

where $G$ is the gravity constant $6.67 \cdot 10^{-11}$ Nm$^2$/kg$^2$ so that (Nyanbuya, 2015; Kralj-Iglič, 2025)

$$\gamma = 1.193 \times 10^9 \text{ kg s}^2/\text{m}^3 \tag{53}$$

To link the constants $\gamma$ and $\varepsilon_G$, we connect the mass and the curvature lump,

$$m = \lambda_{Cm} \langle C \rangle V \tag{54}$$

where $\lambda_{Cm}$ is an unit constant

$$\lambda_{Cm} = \text{kg/m}^2 \tag{55}$$

so that

$$\mathbf{g} = \lambda_{Cm}\mathbf{\Gamma} \tag{56}$$

and (Kralj-Iglič, 2025)

$$\varepsilon_G = \gamma/\lambda_{Cm} = 1.193 \cdot 10^9 \text{s}^2/\text{m}. \tag{57}$$

While the gravitational permittivity $\varepsilon_G$ could be estimated from the gravitational acceleration on the Earth, estimation of the constant $\mu_K$ would require the data on the effect of the movement of a massive flux on another massive flux or the measurement of the velocity of the gravitational waves. Instead we estimated $\mu_K$ from Eq.(47). Some results of the determination of the velocity of the gravitational waves (experimental and theoretical) and the estimated $\mu_K$ are shown in Table 2.

Table 2. Velocity of gravitational waves and the corresponding kinetic permeability of space. $c = 3 \times 10^8$ m/s.

| Reference | Velocity | $\mu_K$ (1/m) |
|---|---|---|
| Van Flanders (1998) | $2 \times 10^{10}$ m/s | $2.10 \times 10^{-30}$ |
| Whitfield (2003) | $c$ | $9.31 \times 10^{-27}$ |
| Fomalont and Kopeikin (2003) | 1.06 $c$ | $8.19 \times 10^{-27}$ |
| Kopeikin and Fomalont (2006) | $c$ | $9.31 \times 10^{-27}$ |
| Luo et al. (2013) | $\leq 1.3 \times 10^{14}$ m/s | $49.3 \times 10^{-27}$ |
| Moffat (2014) | $> c$ | $>9.31 \times 10^{-27}$ |
| Nyanbuya (2015) | $c$ | $9.31 \times 10^{-27}$ |
| Cornish et al. (2017) | (0.55 - 1.42) $c$ | (30.4 - 4.45) $\times 10^{-27}$ |
| Liu et al. (2020) | (0.97 - 1.01) $c$ | (9.78 - 9.02) $\times 10^{-27}$ |
| de Rham and Tolley (2020) | $> c$ | $<9.31 \times 10^{-27}$ |
| Ito (2023) | $> c$ | $<9.31 \times 10^{-27}$ |
| Dai and Stojkovic (2024) | $>> c$ | $<<9.2 \times 10^{-27}$ |
| Delgado et al. (2025) | $> c$ | $<9.31 \times 10^{-27}$ |

# 5 Discussion and Conclusions

We considered gravitation due to the curvature lumps of the space affected by the movement. Following the elegant Maxwell-Heaviside equations originally derived for the electric and magnetic fields, we have stated the gravitational field as a source of a space lump with notably higher average mean curvature than the background. We have introduced a companion kinetic field. Dimensional analysis showed that the unit of this field is 1/s and indicated that the field could be the angular frequency. This seems reasonable as rotational motion produces acceleration that is at the essence of the gravitational effect. We have derived the wave equation and expressed the velocity of the gravitational waves by two parameters: gravitational permittivity and kinetic permeability. We have estimated gravitational permittivity from the Earth's gravitational acceleration. We have estimated the kinetic permeability from gravitational permittivity and velocity of gravitational waves reported in the literature. While some authors claim that the velocity of the gravitational waves equals that of the light, some experimental and theoretical works report considerably different values (Table 2).

We have made a step forward from the 1.st generation model (Kralj-Iglič, 2025) to formulate the equations only with the quantities having units of length and time thereby indicating that the companion field is kinetic. Mass is not explicitly included in the model which is in the spirit of Einstein's notion that the gravitational waves are the movements of the coordinate system (Einstein, 1916). Analogy with Maxwell-Heaviside equations for the gravitational field has been previously proposed by Nyanbuya (2015). The companion field was nominated the gravitomagnetic field and the waves were nominated gravitomagnetic waves. However, in contrast with our model, Nyanbuya (2015) included in his description the mass $m$ and introduced with further development of the theory the Lorenz-like equation including the scalar and vector gravitomagnetic potentials. Our presentation of the Maxwell-Heaviside equations is essentially equivalent to the initial presentation of Nyanbuya (2015), specifically regarding the gravitational field, but deviates in identification of the companion field. Nyanbuya's elaboration of the companion field is based on the formalism of the general theory of relativity, however it retains mass as one of the parameters. Our elaboration of the companion field based on dimensional analysis is simple but includes a bold step in eliminating mass from the formulation of the gravitational field. Instead of a black box parameter - mass - we indicate the origin of the increased density of the substance, i.e. the curvature effects. In this regard, packing of highly curved space formations is associated with greater mass. For simplicity, we have introduced the packing of space with an average value of the curvature, however, the dimension of the parameter $\langle H \rangle$ (i.e. 1/m) was sufficient to eliminate mass and identify as a possible companion field the angular frequency $\mathbf{K} = \Omega$.

The attempts to better understand the origin of the gravitational effects include some modern theories proposing that they derive from entropy (Verlinde, 2011) or torsion of the space-time (Aldrovandi and Pereira, 2013), or thermodynamic effects (Padmanbhan, 2010). In theories involving energy flux or fields (non-mass sources), gravitational effects were described without explicitly emphasizing mass as the sole source, instead focusing on energy -momentum distributions, which can include non-mass energy forms; frame - dragging and the Lense - Thirring effect (Lense and Thirring, 1918) was introduced as the relation of the angular momentum/rotation (which relates to angular frequency) and space-time topology and curvature. Lense and Thirring (1918) formulated the weak-field and slow - motion description of the effect of frame dragging of inertial frames around rotating masses on the orbit of a particle around the spinning body. However, to our best knowledge there are no conclusive results yet on relevant experimental evidences.

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## 7 Conflicts of Interest

The authors disclose no conflict of interest.

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