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A Mode of Electromagnetic Wave Propagation Based on the Inter-induction of Scalar Electric Field and Vortex Magnetic Field

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Abstract: Drawing upon the electromagnetic conversion formulas in a continuous conductive medium, an extensive examination for total current law and Faraday's law of electromagnetic induction (Faraday's law) is undertaken to expound on the laws of electromagnetic induction and conversion. The longitudinal wave term of Faraday's law is reinstated to render it suitable for theoretical derivation of the LEM (Longitudinal Electromagnetic Wave) equation. Subsequently, we formulate the wave and energy equations for electric P-wave based on reevaluated total current law and modified Faraday's law; meanwhile proposing a propagation mode that reveals its mechanisms absorbing free energy for LEM waves in a conductor predicated on interaction between scalar electric field and vortex magnetic field. Furthermore, through theoretical derivations based on LEM waves, insights into concealed relationships between electric P-wave and electromagnetism scalar potential are disclosed alongside the constraint equation between the wave velocities of LEM wave and TEM (Transverse Electromagnetic) waves, unveiling the significance of LEM wave.

Key words: Quantum electrodynamics, LEM, modified Faraday's law of electromagnetic induction, electromagnetic vortex potential, zero-point vacuum energy.

1. Preface

The LEM (Longitudinal Electromagnetic) wave was initially discovered by Maxwell, who unified electricity and magnetism and formulated Maxwell's equations, establishing the theoretical underpinning for modern electromagnetic [1]. In 1890, Tesla detected the LEM wave while refining Hertz's experiment and introduced the concept of scalar field [2]. Subsequently, Meyl conducted extensive research in the domain of LEM waves and proposed that Maxwell's equations have solutions involving longitudinal waves [3-5]. Additionally, Zohuri put forward a quantum electrodynamic theoretical framework for LEM waves [6, 7], Monstein provided their existence from an astrophysical perspective [8, 9], while Oschman suggested that two anti-phase coherent TEM (Transverse Electromagnetic) waves would generate a LEM wave [10]. The exceptional properties of LEM waves, including harmless penetration of the human body, superluminal speed, and absorption of free energy have garnered widespread attention for their potential and practical applications in the fields of medicine, energy and electric power [11-17]. However, the lack of rigorous theoretical models for LEM waves has led to skepticisms regarding their existence and effectiveness [18]. Therefore, establishing robust propagation mode and wave equation for LEM waves is essential for advancing the application of LEM waves. However, current Maxwell's equations neglect the LEM wave item, rendering them incompatible with such waves. It is imperative to reintroduce the longitudinal wave item into Maxwell's equations and develop a rigorous mathematical model for LEM waves, integrating it into the theoretical framework of Maxwell's equations.

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2. The LEM Wave Items and Electromagnetic Symmetry in Faraday's Law and Total Current Law

2.1 The Longitudinal Wave Terms of Total Current Law and Faraday's Law

The conversion formulas governing the inter- of electromagnetic fields within a stationary conductive medium are given as [19]:

$$\vec{E} = -\vec{V}_{\mathrm{B}} \times \vec{B} \tag{1}$$

$$\frac{1}{\mu\varepsilon}\vec{B} = -\vec{V}_{\mathrm{e}} \times \vec{E} \tag{2}$$

where $-\vec{V}_e$ denotes the motion speed of the electric field (current); while $\vec{V}_{\mathrm{B}}$ signifies the phase velocity of TEM waves within the propagation medium, i.e., the velocity of the magnetic field motion. The directions of $-\vec{V}_e$ and $\vec{V}_{\mathrm{B}}$ are shown in Fig. 1. Cross-multiplying both sides of Eq. (2) by ∇ operator gives total current law shown as:

$$\begin{aligned}\nabla \times \vec{B}/\mu\varepsilon &= \partial\vec{E}/\partial t + \vec{J}/\varepsilon \\ &= \partial\vec{E}/\partial t - \left(\nabla \cdot \vec{E}\right)\vec{V}_e \\ &= \partial\vec{E}/\partial t + \vec{E}\,\sigma/\varepsilon = \partial\vec{E}/\partial t + \vec{E}/\tau_1\end{aligned} \tag{3}$$

Here, $\vec{E}/\tau_1$ represents the longitudinal wave term, denoting the contribution of the scalar electric field $\vec{E}$ producing magnetic vortex potential $\vec{B}_s$ in Fig. 2 to $\nabla \times \vec{B}$ in a conductor, τ_1 is the attenuation time constant for $\vec{B}_s$ [4]. Electromagnetic duality suggests that there should exist a dual equation similar to Eq. (3), and by cross-multiplying both sides of Eq. (1) with ∇ operator, we can obtain the modified Faraday's law considering the longitudinal wave term shown as:

$$\begin{aligned}\nabla \times \vec{E} &= \nabla \times \left(-\vec{V}_B \times \vec{B}\right) \\ &= \left(\vec{V}_B \cdot \nabla\right)\vec{B} - \left(\nabla \cdot \vec{B}\right)\vec{V}_B \\ &= -\partial\vec{B}/\partial t - \left(\nabla \cdot \vec{B}\right)\vec{V}_B\end{aligned} \tag{4}$$

Eq. (4) is the dual of Eq. (3). Referring to Eq. (3), Eq. (4) can be rewritten as:

$$\begin{aligned}\nabla \times \vec{E} &= -\partial\vec{B}/\partial t - \left(\nabla \cdot \vec{B}\right)\vec{V}_B \\ &= -\partial\vec{B}/\partial t - \vec{B}_z/\tau_2\end{aligned} \tag{5}$$

In Eq. (5), $\vec{B}_z/\tau_2$ represents the contribution of the scalar magnetic field $\vec{B}_z$ generating electric vortex potential $\vec{E}_{\mathrm{w}}$ in Fig. 3 to $\nabla \times \vec{E}$. Considering the definition of τ_1 as the attenuation time constant for the magnetic vortex potential $\vec{B}_s$ in Fig. 2 shown as:

$$\tau_1 = \varepsilon/\sigma \tag{6}$$

according to literature [4], τ_1 and τ_2 are related to medium's magnetic permeability μ, electrical conductivity σ, and dielectric constant ε. In addition to $\tau_1 = \varepsilon/\sigma$, it can be inferred that τ_2 is related to remaining parameters μ and σ. Using dimensional analysis yields:

$$\tau_2 = \mu\,\sigma/k_0^2 \tag{7}$$

where k_0 is a constant associated with characteristic parameters of medium and electromagnetic waves.

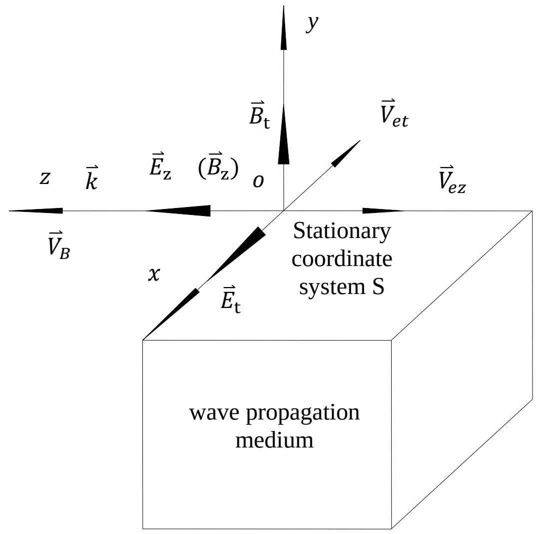

Fig. 1 Electromagnetic field in a continuous medium.

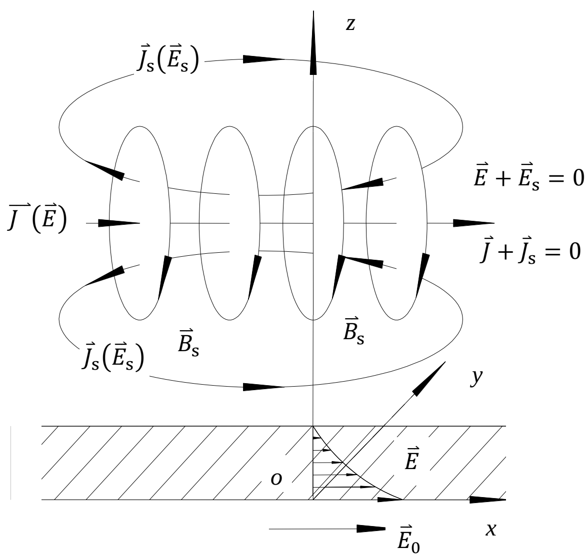

Fig. 2 Magnetic vortex potential in a metal conductor.

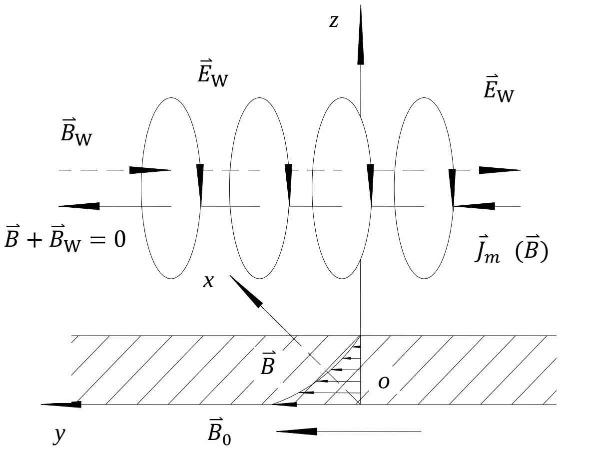

Fig. 3 Electric vortex potential in a metal conductor.

2.2 Expression for k_0

Assuming that the medium for electromagnetic wave propagation is a metal conductor, if the metal conductor is treated as an ideal conductor, i.e., the electrical conductivity σ is infinite, according to Eqs. (6) and (7), we have:

$$\frac{\vec{E}}{\tau_1}=-(\nabla\cdot\vec{E})\ \vec{V}_\mathrm{e}=-\mathrm{j}kE_\mathrm{z}\ \vec{V}_\mathrm{e}=\frac{\sigma}{\varepsilon}\vec{E}=\infty \quad (8)$$

$$\frac{\vec{B}}{\tau_2}=(\nabla\cdot\vec{B})\vec{V}_B=\mathrm{j}kB_\mathrm{z}\ \vec{V}_\mathrm{B}=\frac{\vec{B}}{\mu\sigma}k_0^2=0 \quad (9)$$

Since the ideal conductor's $\vec{B}/\tau_2$ is zero, that is, in Eq. (5), $\vec{B}/\tau_2$ can be ignored. Therefore, we have:

$$\frac{\left|\partial\dot{\vec{B}}/\partial t\right|}{\left|\dot{\vec{B}}/\tau_2\right|}=\tau_2\omega\gg 1 \quad (8.1)$$

By substituting Eqs. (7) into (8.1), we obtain:

$$\tau_2\omega=\frac{\mu\sigma\omega}{k_0^2}\gg 1 \quad (9.1)$$

which is the condition for treating the metal as an ideal conductor. In a metal conductor, when the electromagnetic wave working frequency $\omega\ll\sigma/\varepsilon=10^{17}$ Hz, i.e., $\sigma\gg\omega\varepsilon$, the metal can be treated as a good conductor [20]. The condition for treating the metal as a good conductor is:

$$\frac{\mu\sigma\omega}{k_0^2}\gg\frac{\mu\varepsilon\omega^2}{k_0^2} \quad (9.2)$$

The condition for treating the metal as an ideal conductor (Eq. (9.1)) is higher than the condition for treating the metal as a good conductor (Eq. (9.2)), so $\frac{\mu\varepsilon\omega^2}{k_0^2}\leq 1$, i.e., $k_0\geq\omega\sqrt{\mu\varepsilon}$. Therefore, it is assumed that:

$$k_0=\omega\sqrt{\mu\varepsilon} \quad (9.3)$$

where σ and ε are the electrical conductivity and dielectric constant of the propagation medium, respectively, and ω is the frequency of TEM waves in a stationary propagation medium, which is also the working frequency of the applied electromagnetic field. Substituting Eqs. (9.3) into (7) yields:

$$1/\tau_2=\frac{\omega^2\varepsilon}{\sigma} \quad (10)$$

2.3 The Electromagnetic Symmetry in Maxwell's Equations

In the realm of natural phenomena, electricity and magnetism form an inherent duality, and it is expected that total current law and Faraday's law exhibit elegant physical symmetries. By referencing Eq. (3.1) for total current law, a revision of Eq. (5) for modified Faraday's law to Eq. (5.1) is warranted.

$$\begin{aligned}\frac{1}{\mu\varepsilon}\nabla\times\vec{B}&=\frac{\partial\vec{E}}{\partial t}-(\nabla\cdot\vec{E})\vec{V}_\mathrm{e}=\frac{\partial\vec{E}}{\partial t}-\frac{\rho}{\varepsilon}\vec{V}_\mathrm{e}\\&=\frac{\partial\vec{E}}{\partial t}+\frac{1}{\varepsilon}\ \vec{J}\\&=\frac{\partial\vec{E}}{\partial t}+\frac{\sigma}{\varepsilon}\ \vec{E}\end{aligned} \quad (3.1)$$

$$\begin{aligned}\nabla\times\vec{E}&=-\frac{\partial\vec{B}}{\partial t}-(\nabla\cdot\vec{B})\vec{V}_\mathrm{B}=-\frac{\partial\vec{B}}{\partial t}-\mu\rho_m\vec{V}_\mathrm{B}\\&=-\frac{\partial\vec{B}}{\partial t}-\mu\vec{J}_m\\&=-\frac{\partial\vec{B}}{\partial t}-\frac{\omega^2\varepsilon}{\sigma}\vec{B}_z\end{aligned} \quad (5.1)$$

where ρ and $\vec{J}$ are the free charge density and the conduction current density; ρ_m and $\vec{J}_m$ are the magnetic charge density and the magnetic current density. According to Eqs. (3.1) and (5.1), the charge density and current density ρ and $\vec{J}$, magnetic charge density and magnetic current density ρ_m and $\vec{J}_m$ can be expressed as:

$$\rho = \varepsilon(\nabla \cdot \vec{E}) = \frac{\varepsilon}{V_{ez}} \mathrm{j}\omega_P E_z = \frac{\sigma}{V_{ez}} E_z \qquad (3.2)$$

$$\overrightarrow{J} = -\rho \vec{V}_e = \sigma \ \vec{E} \qquad (3.3)$$

$$\rho_m = \frac{1}{\mu}(\nabla \cdot \vec{B}) = \frac{1}{\mu V_B} \mathrm{j}\omega_P B_z = \frac{\omega^2 \varepsilon}{\mu \sigma V_B} B_z \qquad (5.2)$$

$$\vec{J}_m = \rho_m \vec{V}_B = \frac{1}{\mu} \mathrm{j}\omega_P \vec{B}_z = \frac{\omega^2 \varepsilon}{\mu \sigma} \vec{B}_z \qquad (5.3)$$

Eqs. (3.1) and (5.1) demonstrate the perfect mathematical symmetry and complete electromagnetic symmetry of total current law and modified Faraday's law. According to total current law, the electric scalar $(\overrightarrow{J})$ and the time changing electric field $(\partial \vec{E}/\partial t)$ can generate a vortex magnetic field ($\nabla \times \vec{B}$), while this vortex magnetic field can also produce the electric scalar. On the other hand, as per modified Faraday's law, the magnetic scalar $(\vec{J}_m)$ and the time changing magnetic field ($-\partial \vec{B}/\partial t$) can create a vortex electric field ($\nabla \times \vec{E}$), which in turn is capable of producing a magnetic scalar. It should be noted that current Maxwell's equations do not explicitly address how a vortex magnetic field can give rise to scalar electric field or how a scalar magnetic field can lead to vortex electric field; hence, their representation of electromagnetic induction relationships remains incomplete. The longitudinal wave terms and electromagnetic symmetry analysis related to both two laws are presented in Table 1. Upon comparing Eqs. (3.1) and (5.1) and analyzing Figs. 2 and 3, it becomes evident that mutual conversion between electromagnetic fields is closely linked with vortex electromagnetic fields, where τ_2 represents attenuation time constant for electric vortex potential while τ_1 denotes attenuation time constant for magnetic vortex potential—the two parameters play pivotal roles in electromagnetic conversion.

As per Eq. (3.1) and $\nabla \times \vec{E}_z = \mathrm{j}\vec{k} \times \vec{E}_z = 0$, it follows that $\nabla \cdot \vec{E} = \nabla \cdot \vec{E}_z = \rho/\mathcal{E} \neq 0$, $\nabla \cdot \vec{B}_z = \varepsilon\omega^2 B_z/V_\mathrm{B}\sigma = 0$ and $\vec{E}_z \neq 0$, $\vec{B}_z = 0$ in a metal medium, indicating $\vec{E}_z$ constitutes an active non-vortex field. Assuming the frequency and wave velocity of $\vec{E}_z$ are denoted by ω_P and V_{ez}, from Gauss's law, it is given:

$$\begin{aligned}\nabla \cdot \vec{E} = \nabla \cdot \vec{E}_z = \mathrm{j}kE_z = \mathrm{j}\ \frac{\omega_P}{V_{ez}} E_z \\ = -\mathrm{j}\frac{\rho \ \ \sigma E_z}{-\rho V_{ez}\sigma}\omega_P \\ = -\mathrm{j}\frac{\rho}{\sigma}\omega_P = \frac{\rho}{\varepsilon}\end{aligned} \qquad (3.4)$$

Table 1 The LEM wave items and the electromagnetic conversion laws concealed in total current law and Faraday's law.

	Total current law	Faraday's law
Equation	$\nabla \times \vec{B}/\mu\varepsilon = \partial \vec{E}/\partial t + \overrightarrow{J}/\varepsilon = \partial \vec{E}/\partial t - (\nabla \cdot \vec{E})\ \vec{V}_e = \partial \vec{E}/\partial t + \vec{E}\,\sigma/\varepsilon = \partial \vec{E}/\partial t + \vec{E}/\tau_1$ (3.1)	$\nabla \times \vec{E} = -\partial \vec{B}/\partial t - (\nabla \cdot \vec{B})\vec{V}_B = -\partial \vec{B}/\partial t - \mu\rho_m \vec{V}_\mathrm{B} = -\partial \vec{B}/\partial t - \mu \vec{J}_m = -\partial \vec{B}/\partial t - \vec{B}_z/\tau_2$ (5.1)
Electro-magnetic conversion formulas	$\vec{B}_z/\mu\varepsilon = -\vec{V}_{ez} \times \vec{E}_z$	$\vec{E} = -\vec{V}_B \times \vec{B}$
Connotation of essence	electric field is relativistic effect of magnetic field	magnetic field is relativistic effect of electric field
LEM wave item	$\vec{E}/\tau_1 = \vec{E}\,\sigma/\varepsilon$, the contribution of the scalar electric field $\vec{E}$ generating magnetic vortex potential to $\nabla \times \vec{B}$	$\vec{B}_z/\tau_2 = \vec{B}_z\omega^2\varepsilon/\sigma$, the contribution of the scalar magnetic field $\vec{B}$ generating electric vortex potential to $\nabla \times \vec{E}$
Vortex potential	magnetic vortex potential $\vec{B}_\mathrm{s}$ (vortex-induced magnetic field)	electric vortex potential $\vec{E}_\mathrm{w}$ (vortex-induced electric field)
Other equations	$\partial \vec{E}_z/\partial t = (\vec{V}_{ez} \cdot \nabla)\vec{E}_z = (0,0,\partial z/\partial t) \cdot (\partial/\partial x, \partial/\partial y, \partial/\partial z)\vec{E}_z$, $-(\nabla \cdot \vec{E})\vec{V}_{ez} = \vec{E}_z/\tau_1$ (3.6)	$\partial \vec{B}_z/\partial t = -(\vec{V}_B \cdot \nabla)\vec{B}_z = (0,0,\partial z/\partial t) \cdot (\partial/\partial x, \partial/\partial y, \partial/\partial z)\ \vec{B}_z$, $(\nabla \cdot \vec{B})\ \vec{V}_B = \vec{B}_z/\tau_2$ (5.6)
Electro-magnetic induction	the electric scalar $(\overrightarrow{J})$ and the time changing electric field $(\partial \vec{E}/\partial t)$ can generate a vortex magnetic field ($\nabla \times \vec{B}_s$)	the magnetic scalar $(\vec{J}_m)$ and the time changing magnetic field ($-\partial \vec{B}/\partial t$) can create a vortex electric field ($\nabla \times \vec{E}_\mathrm{w}$)
Magnetic-electric induction	vortex electric field ($\nabla \times \vec{B}_\mathrm{s}$) can induce scalar electric field $\vec{E}_\mathrm{s}$	vortex electric field ($\nabla \times \vec{E}_\mathrm{w}$) can induce scalar magnetic field $\vec{B}_\mathrm{w}$

The frequency of E_z can be determined from Eq. (3.4) as:

$$\omega_P = \mathrm{j}\frac{\sigma}{\varepsilon} = \mathrm{j}/\tau_1 \tag{3.5}$$

In a vacuum, $\nabla \times \vec{B}_z = \mathrm{j}\vec{k} \times \vec{B}_z = 0$. According to Eq. (5.1), we can gain $\nabla \cdot \vec{B}_z = \mathrm{j}\frac{\omega_P}{\mathrm{C}} B_z \neq 0$, indicating that $\vec{B}_z$ also represents an active non-vortex field. Referring to Eqs. (5.1) and (5.2), modified Gauss's magnetic law can be expressed as:

$$\begin{aligned}\nabla \cdot \vec{B} = \nabla \cdot \vec{B}_z = \mathrm{j}\frac{\omega_\mathrm{P}}{\mathrm{C}} B_\mathrm{z} = \varepsilon_0 \omega^2 B_\mathrm{z}/\mathrm{C}\sigma_0 \\ = \mu_0 \rho_m\end{aligned} \tag{5.4}$$

From Eq. (5.4), the frequency of the magnetic P-wave B_z, denoted as ω_P, is given by:

$$\omega_\mathrm{P} = -\mathrm{j}\frac{\omega^2 \varepsilon_0}{\sigma_0} = -\mathrm{j}/\tau_2 \tag{5.5}$$

As expressed in Eqs. (3.4) and (5.4), the electromagnetic symmetry of Gauss's law and modified Gauss's magnetic law is unveiled.

3. The Foundational Equations of LEM Waves

The wave equation for electromagnetic wave, formulated with Eqs. (3.1) and (5.1) as its foundational equations, is expressed as:

$$\begin{aligned}-\frac{1}{\mu\varepsilon}\nabla \times \left(\nabla \times \vec{E}\right) &= -\frac{1}{\mu\varepsilon}\nabla\left(\nabla \cdot \vec{E}\right) + \frac{1}{\mu\varepsilon}\nabla^2 \vec{E} \\ &= \frac{\partial^2 \vec{E}}{\partial t^2} + \frac{1}{\tau_1}\frac{\partial \vec{E}}{\partial t} + \frac{1}{\tau_2}\frac{\partial \vec{E}_z}{\partial t} \\ &+ \frac{\vec{E}_z}{\tau_2 \tau_1}\end{aligned} \tag{11}$$

For TEM waves, since $\nabla \cdot \vec{E} = 0$, the projection of Eq. (11) along the transverse direction of electromagnetic wave propagation in Fig. 1 gives the TEM wave equation in a metal shown as:

$$\nabla^2 \vec{E}_t - \mu\varepsilon\frac{\partial^2 \vec{E}_t}{\partial t^2} - \mu\sigma\frac{\partial \vec{E}_t}{\partial t} = 0 \tag{12}$$

with the basic equations expressed as:

$$\begin{aligned}\nabla \times \vec{B}_t/\mu\varepsilon = \partial \vec{E}_t/\partial t \\ -\big(\nabla \\ \cdot \vec{E}_z\big)\vec{V}_{et} = \partial \vec{E}_t/\partial t + \frac{\sigma}{\varepsilon}\ \vec{E}_t\end{aligned} \tag{3.7}$$

$$\nabla \times \vec{E}_t = -\,\partial \vec{B}_t/\partial t \tag{5.7}$$

while the fundamental equations for LEM waves in a conductor can be expressed as follows:

$$\begin{aligned}\nabla \times \vec{B}_z/\mu\varepsilon = \partial \vec{E}_z/\partial t - \big(\nabla \cdot \vec{E}_z\big)\vec{V}_{ez} \\ = \partial \vec{E}_z/\partial t + \sigma\ \ \vec{E}_z/\varepsilon = 0\end{aligned} \tag{13}$$

$$\begin{aligned}\nabla \times \vec{E} = -\big(\nabla \cdot \vec{B}\big)\vec{V}_B = -\vec{B}_z/\tau_2 = -\frac{\omega^2 \varepsilon}{\sigma}\vec{B}_z \\ = 0\end{aligned} \tag{3.9}$$

$$\nabla \cdot \vec{E} = \nabla \cdot \vec{E}_z = \mathrm{j}kE_z = \mathrm{j}\ \frac{\omega_P}{V_{ez}} E_z = \frac{\rho}{\varepsilon} \neq 0 \tag{3.4}$$

$$\nabla \cdot \vec{B} = \nabla \cdot \vec{B}_z = \varepsilon\omega^2 B_\mathrm{z}/(V_\mathrm{B}\sigma) = 0 \tag{5.4}$$

$$\nabla \times \vec{B}/\mu\varepsilon = \sigma\ \ \vec{E}_z/\varepsilon \neq 0 \tag{5.8}$$

Here, ω_P can be utilized for determining the frequency of E_z. Eqs. (3.8) and (3.4) demonstrate that the electric P-wave $\vec{E}$ within a conductor is an active non-vortex field, while Eqs. (5.4) and (5.8) reveal that the magnetic P-wave $\vec{B}$ in a conductor is a passive vortex field, i.e., $\vec{B} = \vec{B}_\theta$, $\vec{E} = \vec{E}_z$.

4. Propagation Mode for Electric P-Wave

4.1 The Wave Equation of Electric P-Wave

For LEM waves, $\nabla \cdot \vec{E} = \nabla \cdot \vec{E}_z \neq 0$, when projected onto the axial direction of electromagnetic wave propagation (*z*-axis in Fig. 1), Eq. (11) yields:

$$\begin{aligned}-\frac{1}{\mu\varepsilon}\nabla \times \left(\nabla \times \vec{E}_z\right) &= -\frac{1}{\mu\varepsilon}\nabla\left(\nabla \cdot \vec{E}_z\right) + \frac{1}{\mu\varepsilon}\nabla^2 \vec{E}_z \\ &= 0 \\ &= \frac{\partial^2 \vec{E}_z}{\partial t^2} + \frac{1}{\tau_1}\frac{\partial \vec{E}_z}{\partial t} + \frac{1}{\tau_2}\frac{\partial \vec{E}_z}{\partial t} + \frac{\vec{E}_z}{\tau_2 \tau_1}\end{aligned} \tag{14}$$

If the propagation medium is a good conductor, it can be assumed that σ tends to infinity. From Eqs. (3.2) and (5.2), we can deduce that $\rho \neq 0$, $\rho_m = 0$. From Eqs. (3.4) and (5.4), we can obtain that $\nabla \cdot \vec{E} \neq 0$ and $\nabla \cdot \vec{B} = 0$, i.e.,

$$B_\mathrm{z} = 0 \text{ and } E_z \neq 0 \tag{15}$$

A good conductor satisfies $\sigma/\omega\varepsilon \gg 1$. Therefore, in Eq. (14), $\left|\frac{1}{\tau_2}\frac{\partial \vec{E}_z}{\partial t}\right| / \left|\frac{1}{\tau_1}\frac{\partial \vec{E}_z}{\partial t}\right|$ is equal to $(\omega\varepsilon/\sigma)^2 \ll 1$, while $\left|\frac{1}{\tau_1}\frac{\partial \vec{E}_z}{\partial t}\right| / \left|\frac{\vec{E}_z}{\tau_2 \tau_1}\right|$ equals $\left(\frac{\sigma}{\omega\varepsilon}\right)^2 \gg 1$.

Consequently, $\frac{1}{\tau_2}\frac{\partial \vec{E}_z}{\partial t}$ and $\frac{\vec{E}_z}{\tau_2\tau_1}$ can be disregarded in Eq. (14) that can be simplified as:

$$\frac{\partial^2 \vec{E}_z}{\partial t^2} + \frac{1}{\tau_1}\frac{\partial \vec{E}_z}{\partial t} = 0 \tag{16}$$

From Eq. (3.6), it is given that $\frac{1}{\tau_1}\frac{\partial \vec{E}_z}{\partial t} = (\vec{V}_{ez}\cdot\nabla)\vec{E}_z/\tau_1 = -(\vec{V}_{ez}\cdot\nabla)[(\nabla\cdot\vec{E}_z)\vec{V}_{ez}] = -V_{ez}^2\frac{\partial^2 \vec{E}_z}{\partial z^2}$, i.e.,

$$\frac{\partial^2 \vec{E}_z}{\partial t^2} - V_{ez}^2\frac{\partial^2 \vec{E}_z}{\partial z^2} = 0 \tag{16.1}$$

with a plane solution expressed as:

$$\vec{E}_z = \vec{E}_{z0}\exp\left[\text{ j }\left(\frac{\omega_P}{V_{ez}}z - \omega_P t\right)\right] \tag{16.2}$$

Here, ω_P represents the frequency of E_z, while $-\vec{V}_{ez}$ denotes the phase velocity of E_z.

4.2 The Propagation Mode of Electric P-Wave

Referring to the fundamental equations for a TEM wave in a metal conductor Eqs. (3.7) and (5.7), from Eq. (4) , it can be inferred that within a metal conductor, $\vec{E}_z$ can be converted into its magnetic counterpart $\vec{B}_\theta$ through their specific relationship shown as:

$$\vec{E}_z = -\vec{V}_B \times \vec{B}_\theta \tag{16.3}$$

$$\begin{aligned}\frac{1}{\mu\varepsilon}\nabla\times\vec{B}_\theta &= \frac{1}{\mu\varepsilon}\text{j}\vec{k}\times\vec{B}_\theta = \frac{1}{\mu\varepsilon}\text{j}\frac{\omega_P}{V_{ez}}B_\theta\vec{e}_z = \frac{\vec{E}_z}{\tau_1}\\ &= \frac{1}{\tau_1}E_{z0}\vec{e}_z\exp\left[\text{ j }\left(\frac{\omega_P}{V_{ez}}z - \omega_P t\right)\right]\end{aligned} \tag{16.4}$$

which gives that:

$$\begin{aligned}\vec{B}_\theta &= \mu\varepsilon V_{ez}\frac{E_{z0}}{\omega_P\tau_1}\exp\left[\text{ j }\left(\frac{\omega_P}{V_{ez}}z - \omega_P t - \frac{\pi}{2}\right)\right]\vec{e}_\theta\\ &= \mu\varepsilon V_{ez}E_{z0}\exp\left[\text{ j }\left(\frac{\omega_P}{V_{ez}}z - \omega_P t - \frac{\pi}{2}\right)\right]\vec{e}_\theta\end{aligned} \tag{16.5}$$

Eqs. (3.5) and (16.3) are substituted into Eq. (16.4), it is obtained that:

$$\frac{1}{\mu\varepsilon}\nabla\times\vec{B}_\theta = \frac{\vec{E}_z}{\tau_1} = -\frac{1}{\tau_1}\vec{V}_B\times\vec{B}_\theta = \text{j}\omega_P V_B\vec{e}_z\times\vec{B}_\theta = \frac{1}{\mu\varepsilon}\text{j}k\vec{e}_z\times\vec{B}_\theta = \frac{1}{\mu\varepsilon}\text{j}\frac{\omega_P}{V_{ez}}\vec{e}_z\times\vec{B}_\theta, \text{ i.e.,} \tag{17}$$

$$\frac{1}{\mu\varepsilon} = V_{ez}V_B$$

Substituting Eq. (17) back to Eq. (16.5) yields:

$$\vec{B}_\theta = \frac{E_{z0}}{V_B}\exp\left[\text{ j }\left(\frac{\omega_P}{V_{ez}}z - \omega_P t - \frac{\pi}{2}\right)\right]\vec{e}_\theta \tag{18}$$

Eqs. (16.2) and (18) represent solutions to the wave equations governing the LEM waves $\vec{B}_\theta$ and $\vec{E}_z$. The propagation model for $\vec{B}_\theta$ and $\vec{E}_z$ is depicted in Fig. 4, illustrating that the phase angle of $\vec{B}_\theta$ lags behind $\vec{E}_z$ by 90°. The conversion process from the vortex magnetic field $\vec{B}_\theta$ into a scalar electric field $\vec{E}_z$ is illustrated in Fig. 4 as O to A and B to C, while the transformation from $\vec{E}_z$ into $\vec{B}_\theta$ is shown as A to B and C to D. This cyclic process involves alternating induction and conversion between $\vec{B}_\theta$ and $\vec{E}_z$, propagating along the *z*-axis with a positive direction at phase velocity V_{ez}, which is a more fundamental mode of electromagnetic wave propagation that has been overlooked because Maxwell's equations neglect the longitudinal wave term.

As shown in Fig. 4, the vortex motion of point O to A forms a singularity at point A, resembling a black hole, where all magnetic energy is drawn. Similar to the inception of the Big Bang from a singularity, upon reaching point A, a white hole emerges adjacent to the

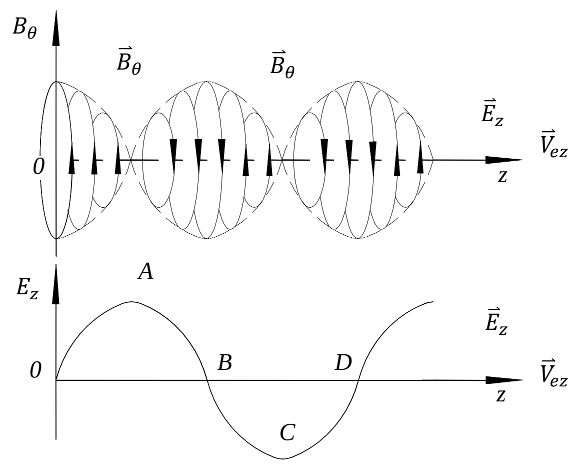

Fig. 4 A schematic diagram of the propagation model of ELM in a conductor.

black hole, releasing all absorbed magnetic energy in a spiral from zero and initiating a new cycle of energy (cosmic life). According to the law of electromagnetic induction, the electric P-wave E_z can produce the magnetic vortex potential whose vortex motion interacts with zero-point vacuum energy field to form a entangled TF that might generate high-energy rays, neutrons, and high-energy particles at its vortex center and extract free energy, accompanied by highly directed cold fusion [21, 22]. This process enables ELM waves to acquire significantly free energy.

4.3 The Energy Equation of Electric P-Wave

The total energy E_T associated with two source TEM waves with identical frequency, amplitude, and propagation direction, but a phase difference of π in a conductor can be represented as:

$$\begin{aligned} E_T &= \int_\Omega -\varepsilon\frac{\partial(E_1^2)}{\partial t} - \varepsilon\frac{\partial(E_2^2)}{\partial t}\mathrm{d}\Omega \\ &= \int_\Omega 4\omega\varepsilon_0 E_0^2 \exp^2(-\alpha z)\sin 2(\beta z - \omega t)\mathrm{d}\Omega \\ &= 4\Omega\omega\varepsilon_0 E_0^2\overline{\exp^2}(-\alpha z) \\ &= 4\Omega\omega\varepsilon_0 E_0^2\overline{\exp^2}\left(-\frac{\omega}{V_B}z\right) \end{aligned} \quad (20)$$

Here, $\overline{\exp^2}(-\alpha z)$ represents the spatial average value of $\exp^2(-\alpha z)$ on the integration domain Ω, ω is the frequency of source TEM waves. After their superposition, the resultant electromagnetic fields both equal zero, seemingly leading to a disappearance of energy. However, according to the law of energy conservation, before/after the superposition, E_T should be converted to the energy of $\vec{E}_z$ expressed as:

$$\begin{aligned} E_P &= \int_\Omega -\frac{\varepsilon}{2}\frac{\partial(E_{z)}^2}{\partial t}\mathrm{d}\Omega = \\ &= \int_\Omega \left(-\frac{1}{2\mu}\frac{\partial(B_\theta^2)}{\partial t}\right)\mathrm{d}\Omega \\ &= \mathrm{j}\omega_P\varepsilon E_{z0}^2\int_\Omega \exp^2\left[\mathrm{j}\left(\frac{\omega_P}{V_{ez}}z - \omega_P t\right)\right]\mathrm{d}\Omega \\ &= \Omega\omega_P\varepsilon E_{z0}^2 \\ &= 4\Omega\omega_P\varepsilon E_0^2\exp^2(-\alpha z) \end{aligned} \quad (21)$$

5. Discussion

5.1 Validation of $k_0 = \omega\sqrt{\mu\varepsilon}$

Eqs. (3.5) and (5.5) yield $\frac{1}{\tau_1} = -\mathrm{j}\omega$ and $\frac{1}{\tau_2} = \mathrm{j}\omega$, while Eqs. (6) and (10) give that $\tau_1 = \frac{\varepsilon}{\sigma}$ and $\tau_2 = \frac{\mu\sigma}{k_0^2}$. Multiplying these expressions results in $\frac{1}{\tau_1}\frac{1}{\tau_2}\tau_1\tau_2 = 1 = \omega\omega\frac{\mu\sigma}{k_0^2}\frac{\varepsilon}{\sigma} = \frac{\mu\varepsilon\omega^2}{k_0^2}$, leading to the conclusion that:

$$k_0 = \omega\sqrt{\mu\varepsilon}. \quad (22)$$

Thus, assumption of Eq. (9.3) in Section 1.2 holds true.

5.2 Characteristics of Electric P-Wave

5.2.1 The Superluminal Propagation

According to the Lorentz gauge in a metal conductor, we have $\nabla\cdot\vec{A} = -\mu\varepsilon\,\partial\varphi/\partial t = \mu\varepsilon\mathrm{j}\omega_P V_B A_z = \frac{\mathrm{j}\omega_P A_z}{V_{ez}}$, which leads to:

$$1/\mu\varepsilon = V_{ez}V_B \quad (24)$$

Eq. (24) represents the constraint equation governing the wave speeds of LEM and TEM waves. Here, V_{ez} denotes the phase velocity of the electric P-wave E_z, while V_B signifies the phase velocity of TEM wave $\vec{E}_t$. For typical metal materials [20], with $\varepsilon\sim 10^{-11}$ F/m, $\mu\sim 10^{-6}$ H/m, $\sigma\sim 10^7$ S/m, taking $\omega = 10^{13}$ Hz $\ll \sigma/\varepsilon \sim 10^{17}$ Hz yields $V_B = \sqrt{\frac{2\omega}{\mu\sigma}}\sim 10^6$ S/m and

$$V_{ez}\sim 10^{10}\,\mathrm{S/m} \gg V_B \quad (25)$$

Eq. (25) indicates that in a metal medium, electric P-wave E_z exhibits superluminal behavior [5], rendering it impossible for metal mediums to shield E_z. Based on the aforementioned analysis, it can be inferred that a clear elucidation of the electromagnetic essence relationships described by Eq. (24) is essential for a comprehensive understanding, necessitating consideration of electric P-wave E_z.

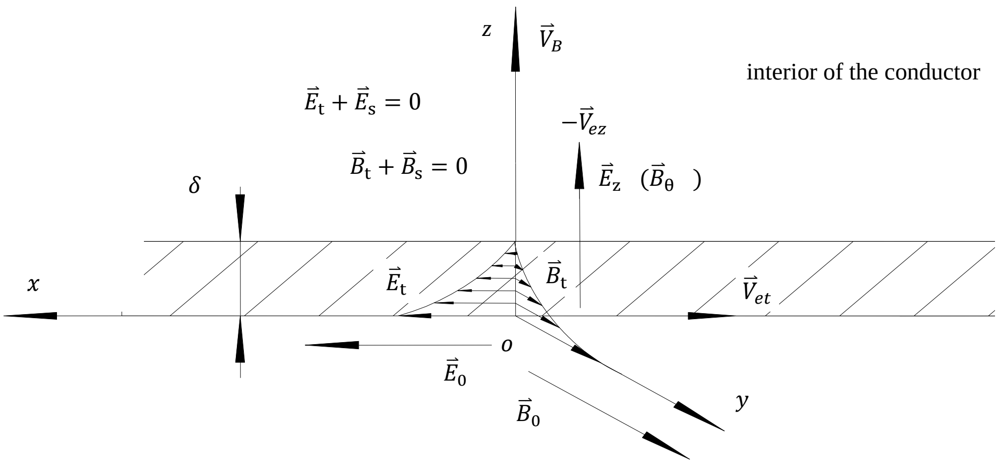

Fig. 5 The ELM and TEM waves in the conductive medium.

5.2.2 Frequency

In typical metallic materials [20], where $\varepsilon \sim 10^{-10}$ F/m and $\sigma \sim 10^{7}$ S/m, their substitution into Eq.(3.5) yields the frequency of electric P-wave E_z as:

$$|\omega_P| = \left|-j\frac{\sigma}{\varepsilon}\right| = 10^{17}\text{Hz}. \tag{26}$$

5.2.3 Outstanding Conductive material Penetration Capacity

The schematic diagrams in Fig. 4 illustrate the propagation of electric P-wave and TEM waves within a stationary conductive medium. Owing to the skin effect, TEM waves are unable to penetrate the conductive medium and can only propagate within a thin layer δ on its surface [23]. The frequency ω_P of the electric P-wave E_z is approximately 10^{17} Hz, while the typical metal's plasma resonance frequency ω_z is on the order of 1×10^{15} Hz, and the average damping coefficient γ_s of bound electrons is around 1×10^{13} Hz. Substituting these parameters [24] into the classical Drude equation [25], yields a dielectric constant ε_r for metal corresponding to frequency ω_P as $\varepsilon_r = 1 - \frac{\omega_z^2}{\gamma_s^2+\omega_P^2} + j\frac{\omega_z^2\gamma_s}{\omega_P(\gamma_s^2+\omega_P^2)} \approx 1$. Under these circumstances, it becomes evident that a conductive medium cannot effectively shield against LEM waves; thus, they exhibit "high-frequency transparency" [26, 27] and have unhindered ability to permeate through human tissue.

5.2.4 The Ability to Absorb Free Energies

According to Eqs. (20) and (21), the ratio of the energy per unit volume of LEM wave to TEM waves can be expressed as:

$$\lim_{\Omega\to 0}\frac{E_P/\Omega}{E_T/\Omega} = \frac{E_P}{E_T} = \lim_{\Omega\to 0}\frac{\omega_P}{\omega}\frac{\exp^2(-\alpha z)}{\exp^2(-\alpha z)} = \frac{\omega_P}{\omega} = \frac{10^{17}\text{Hz}}{10^{13}\text{Hz}} = 10^4. \tag{27}$$

In accordance with Eq. (27), the energy of the electric P-wave is 10^4 times that of the source TEM waves. The mechanism for the additional energy generated by the electric P-wave is likely associated with the vortex-magnetic field B_θ, which has the capability to extract free energy through the interaction between the zero-point vacuum energy field and the torsion field produced by B_θ.

6. Conclusion

Building upon the reevaluated total current law and modified Faraday's law, we formulate the propagation mode and wave equation for electric P-wave. Additionally, through theoretical derivation, we have unveiled the constraint equation governing LEM and TEM wave speeds in a conductor—previously concealed behind Faraday's law and total current law. These research findings underscore the significance of LEM waves and illustrate their superluminal properties, exceptionally harmless human tissue penetration abilities, and capacities for absorption of zero-point vacuum energy, thereby revealing a more profound electromagnetic essence than TEM waves. Developing a rigorous propagation mode for LEM waves along with corresponding energy equation from the system of current Maxwell's equations can offer theoretical backing and optimization techniques for employing these waves in medical treatment. Moreover, advancements in the research of LEM waves offer potential solutions to challenging issues within fields such as wireless power transmission [13], electromagnetic near-field, vacuum zero-point energy [28], neutrinos [29], and TF [22, 30].

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Competing Interests

Authors declare that they have no competing interests.

Data and Materials Availability

All data are available in the main text or the supplementary materials.

Ethical Approval Statement

The study did not require ethical approval.

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