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Interaction of Complex Scalar Fields and Electromagnetic Fields in Klein-Gordon-Maxwell Theory in Cosmological Inertial Frame

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Abstract: *We found equations of complex scalar fields and electromagnetic fields on interaction of complex scalar fields and electromagnetic fields in Klein-Gordon-Maxwell theory from Type A of wave function and Type B of expanded distance in cosmological inertial frame.*

Keywords: *Klein-Gordon-Maxwell Theory; Cosmological Inertial Frame; Complex Scalar fields; Electromagnetic fields*

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1. Introduction

The Lagrangian L of complex scalar fields ϕ,ϕ^* and Electromagnetic fields $F^{\mu\upsilon},F_{\mu\upsilon}$ is Klein-Gordon-Maxwell theory in special relativity theory,

$$L=(\partial_\mu\phi+ieA_\mu\phi)(\partial^\mu\phi^*-ieA^\mu\phi^*)-\frac{m^2c^2}{\hbar^2}\phi\phi^*-\frac{1}{4}F^{\mu\upsilon}F_{\mu\upsilon}$$

ϕ^* is ϕ's adjoint scalar, m is the mass of scalar fields ϕ,ϕ^*

$$F^{\mu\upsilon}=\partial^\mu A^\upsilon-\partial^\upsilon A^\mu,F_{\mu\upsilon}=\partial_\mu A_\upsilon-\partial_\upsilon A_\mu \quad (1)$$

2. Equations of Interaction of Complex Scalar Fields and Electromagnetic Fiel ds in Cosmological Inertial Frame

The Lagrangian L of interaction of complex scalar fields and Electromagnetic fields is Klein-Gordon-Maxwell theory in cosmological inertial frame,

$$L=(\bar{\partial}_\mu\phi+ie\bar{A}_\mu{}'\phi)(\bar{\partial}^\mu\phi^*-ie\bar{A}^\mu{}'\phi^*)-\frac{m^2c^2}{\hbar^2}\phi\phi^*-\frac{1}{4}F^{\mu\upsilon}{}'F_{\mu\upsilon}{}' \quad (2\text{-}1)$$

We consider Type A of wave function and Type B of expanded distance,[1],[2],[3],[4]

Type A of wave function: $r\to r\sqrt{\Omega(t_0)}$, $t\to\frac{t}{\sqrt{\Omega(t_0)}}$,

Type B of expanded distance: $r\to r\Omega(t_0),t\to t$

$$\bar{\partial}_\mu=(\sqrt{\Omega(t_0)}\frac{\partial}{c\partial t},\frac{1}{\sqrt{\Omega(t_0)}}\vec{\nabla}),\bar{\partial}^\mu=(\sqrt{\Omega(t_0)}\frac{\partial}{c\partial t},-\frac{1}{\sqrt{\Omega(t_0)}}\vec{\nabla})$$

$$\bar{A}_\mu{}'=(\phi,\vec{A}\Omega(t_0)),\bar{A}^\mu{}'=(\phi,-\vec{A}\Omega(t_0)),\bar{F}_{\mu\upsilon}{}'=F_{\mu\upsilon}\Omega(t_0),\bar{F}^{\mu\upsilon}{}'=F^{\mu\upsilon}\Omega(t_0)$$

t_0 is the cosmological time. $\Omega(t_0)$ is the expanding ratio of universe in the cosmological time t_0.

(2-2)

Complex scalar field equations are in Klein-Gordon-Maxwell theory in cosmological inertial frame,

$$\bar{\partial}_\mu(\frac{\partial L}{\partial(\bar{\partial}_\mu \phi)})-\frac{\partial L}{\partial \phi}=(\bar{\partial}_\mu-ie\bar{A}_\mu')(\bar{\partial}^\mu\phi^*-ie\bar{A}^\mu{}'\phi^*)+\frac{m^2c^2}{\hbar^2}\phi^*=0 \tag{3}$$

The other equation is in Klein-Gordon-Maxwell theory in cosmological inertial frame,

$$\bar{\partial}_\mu(\frac{\partial L}{\partial(\bar{\partial}_\mu \phi^*)})-\frac{\partial L}{\partial \phi^*}=(\bar{\partial}^\mu+ie\bar{A}^\mu{}')(\bar{\partial}_\mu\phi+ie\bar{A}_\mu{}'\phi)+\frac{m^2c^2}{\hbar^2}\phi=0 \tag{4}$$

If operator $\bar{\partial}_\mu{}',\bar{\partial}^\mu{}'$ are in cosmological inertial frame,[1],[2],[3],[4]

$$\bar{\partial}_\mu{}'=(\frac{\partial}{c\partial t},\frac{1}{\Omega(t_0)}\vec{\nabla}),\bar{\partial}^\mu{}'=(\frac{\partial}{c\partial t},-\frac{1}{\Omega(t_0)}\vec{\nabla})$$

$$\bar{F}^{\mu\upsilon}{}'=\bar{\partial}^\mu{}'\bar{A}^\upsilon{}'-\bar{\partial}^\upsilon{}'\bar{A}^\mu{}',\bar{F}_{\mu\upsilon}{}'=\bar{\partial}_\mu{}'\bar{A}_\upsilon{}'-\bar{\partial}_\upsilon{}'\bar{A}_\mu{}' \tag{5}$$

Electromagnetic field equations are in Klein-Gordon-Maxwell theory in cosmological inertial frame,

$$\bar{\partial}_\upsilon{}'(\frac{\partial L}{\partial(\bar{\partial}_\upsilon{}'\bar{A}_\mu{}')})-\frac{\partial L}{\partial\bar{A}_\mu{}'}=\frac{1}{4}\bar{\partial}_\upsilon{}'(\bar{\partial}^\mu{}'\bar{A}^\upsilon{}'-\bar{\partial}^\upsilon{}'\bar{A}^\mu{}')-ie\phi(\bar{\partial}^\mu\phi^*-ie\bar{A}^\mu{}'\phi^*)+ie\phi^*(\bar{\partial}^\mu\phi+ie\bar{A}^\mu{}'\phi)$$

$$=\frac{1}{4}\bar{\partial}_\upsilon{}'\bar{F}^{\mu\upsilon}{}'-ie\phi(\bar{\partial}^\mu\phi^*-ie\bar{A}^\mu{}'\phi^*)+ie\phi^*(\bar{\partial}^\mu\phi+ie\bar{A}^\mu{}'\phi)=0 \tag{6}$$

Hence,[5],[6]

$$\bar{\partial}_\upsilon{}'\bar{F}^{\mu\upsilon}{}'=-4\pi e\bar{J}^\mu{}'=4ie[\phi(\bar{\partial}^\mu\phi^*-ie\bar{A}^\mu{}'\phi^*)-\phi^*(\bar{\partial}^\mu\phi+ie\bar{A}^\mu{}'\phi)]$$

$$\bar{J}^\mu{}'=-\frac{1}{\pi}i[\phi(\bar{\partial}^\mu\phi^*-ie\bar{A}^\mu{}'\phi^*)-\phi^*(\bar{\partial}^\mu\phi+ie\bar{A}^\mu{}'\phi)]$$

$$=\frac{1}{\pi}i[\phi^*(\bar{\partial}^\mu\phi+ie\bar{A}^\mu{}'\phi)-\phi(\bar{\partial}^\mu\phi^*-ie\bar{A}^\mu{}'\phi^*)] \tag{7}$$

The other equation is in Klein-Gordon-Maxwell theory in cosmological inertial frame,

$$\bar{\partial}^\upsilon{}'(\frac{\partial L}{\partial(\bar{\partial}^\upsilon{}'\bar{A}^\mu{}')})-\frac{\partial L}{\partial\bar{A}^\mu{}'}$$

$$=\frac{1}{4}\bar{\partial}^\upsilon{}'(\bar{\partial}_\mu{}'\bar{A}_\upsilon{}'-\bar{\partial}_\upsilon{}'\bar{A}_\mu{}')+ie\phi^*(\bar{\partial}_\mu\phi+ie\bar{A}_\mu{}'\phi)-ie\phi(\bar{\partial}_\mu\phi^*-ie\bar{A}_\mu{}'\phi^*)$$

$$=\frac{1}{4}\bar{\partial}^\upsilon{}'\bar{F}_{\mu\upsilon}{}'+ie\phi^*(\bar{\partial}_\mu\phi+ie\bar{A}_\mu{}'\phi)-ie\phi(\bar{\partial}_\mu\phi^*-ie\bar{A}_\mu{}'\phi^*)=0 \tag{8}$$

Hence,[5],[6]

$$\bar{\partial}^{\upsilon}{}'\bar{F}_{\mu\upsilon}{}' = -4\pi e\bar{J}_{\mu}{}' = -4ie[\phi^{*}(\bar{\partial}_{\mu}\phi + ie\bar{A}_{\mu}{}'\phi) - \phi(\bar{\partial}_{\mu}\phi^{*} - ie\bar{A}_{\mu}{}'\phi^{*})]$$

$$\bar{J}_{\mu}{}' = i\frac{1}{\pi}[\phi^{*}(\bar{\partial}_{\mu}\phi + ie\bar{A}_{\mu}{}'\phi) - \phi(\bar{\partial}_{\mu}\phi^{*} - ie\bar{A}_{\mu}{}'\phi^{*})] \qquad (9)$$

3. Conclusion

We found equations of complex scalar fields and electromagnetic fields on interaction of complex scalar fields and electromagnetic fields in Klein-Gordon-Maxwell theory from Type A of wave function and Type B of expanded distance in cosmological inertial frame.

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