АСТРОФИЗИКА

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TETRAD FORMULATION OF THE BASIC EQUATIONS OF TYPE II SUPERCONDUCTORS IN CURVED SPACE-TIME

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The basic equations of type II superconductors have been obtained by adopting London's phenomenological approach. The generation of the electromagnetic field in a superconductor at rest in a stationary universe has been investigated using the method of anholonomic frames. The Newtonian formulation of the problem has also been studied.

Key words: *superconductors: basic equations*

1. *Introduction.* In a recent note [1] we discussed some aspects of the electrodynamics of the superconductors in stationary space-time adopting the method of anholonomic frames, when the intensity of the applied magnetic field H is less than the critical value H_{c1}. From the anholonomic form of London's equations we derived the expressions of the electric and magnetic fields generated by a stationary gravitational field inside a superconductor at rest. These fields being determined by the nonzero components of the object of anholonomity. This mathematical object conveys the information on the gravitational field.

The purpose of this note is to extend this anholonomic approach to the discussion of type II superconductors in a stationary universe, when the inequality $H > H_{c1}$ is satisfied. We shall see that the presence of vortices has an influence on the generation of the electromagnetic field inside the superconductor. Whereas the magnetic field is conditioned by the presence of vortices, the generation of electric field, because of the phenomenon of unipolar induction, is related to the motion of magnetic vortices.

In section 2, assuming that the only forces acting on the electronic fluid are the Lorentz force and the reaction of the Magnus force, we adopt London's approach to derive the covariant London equations describing the motion of superelectrons in type II superconductors. In section 3 the tetrad formulation of the above equations is given. They are exhibited in the same form as the corresponding covariant equations with an added term containing the object of anholonomity C. The expression of the electric and magnetic fields generated inside the superconductor are written in terms of the nonzero components of C and of quantities characterizing the structure of vortices. In section 4, we discuss the Newtonian approach of the problem under consideration. This Newtonian formulation has the advantage of clarifying the physical meaning of the obtained results. In section 5, as a concluding remark we mention a possible astrophysical application of the above results.

2. *Holonomic formulation.* Following London let us consider free particles of charge q $(q<0)$ and mass m moving without friction and subject only to the action of the electromagnetic field. The particles are assumed to form a nonviscous charged liquid whose velocity field $u^{\alpha}(x^{\beta})$ satisfies the equation

$$u^{\mu}\left[\partial_{[\mu}u_{\nu]}+\frac{q}{mc^2}F_{\mu\nu}-\frac{q}{mc^2}s_{\mu\nu}\right]=0. \tag{2.1}$$

This equation is obtained by considering the motion of a fictitious charged particle (q, m) subject to the Lorentz force and the reaction of the Magnus force, i. e

$$\frac{\nabla u^{\mu}}{dS}=\frac{q}{mc^2}F^{\nu\mu}u_{\mu}-\frac{q}{mc^2}s^{\nu\mu}u_{\mu}, \tag{2.2}$$

where u_{μ} and $F^{\nu\mu}$ are respectively the unit 4-velocity $(u^{\mu}u_{\mu}=1)$ and the electromagnetic field tensor related to the 4-potential A_{μ} by

$$F_{\mu\nu}=\partial_{\mu}A_{\nu}-\partial_{\nu}A_{\mu}. \tag{2.3}$$

The antisymmetric tensor $s_{\mu\nu}$ may be expressed in terms of quantities characterizing the system of vortices [2]:

$$s_{\mu\nu}=\frac{1}{2}s\,\eta_{\mu\nu\rho\sigma}D^{\rho\sigma},$$

$$D^{\mu\nu}=-u^{\mu}(L)v^{\nu}(L)+u^{\nu}(L)v^{\mu}(L), \tag{2.4}$$

where

$$\eta_{\nu\mu\rho\sigma}=-\sqrt{-g}\,\varepsilon_{\nu\mu\rho\sigma},\quad \eta^{\nu\mu\rho\sigma}=\frac{1}{\sqrt{-g}}\varepsilon_{\nu\mu\rho\sigma}, \tag{2.5}$$

$\varepsilon_{\nu\mu\rho\sigma}$ being the usual permutation symbol and

$$s^2=\frac{1}{2}s^{\mu\nu}s_{\mu\nu}, \tag{2.6}$$

where the scalar s is proportional to the proper density of vortices and $u^{\mu}(L)$, $v^{\mu}(L)$ are respectively the unit 4-velocity of the vortices and the unit 4-vector pointing along the direction of the vortex. The second term on the right hand side of Eq.(2.2) represents the force exerted by the vortex on the fictitious particles (q, m).

Using the fact that $u^{\mu}\nabla_{\nu}u_{\mu}=0$, Eq.(2.2) may be exhibited in the form (2.1). According to London the transition from the nonviscous liquid to the superconductor is performed by replacing (2.1) by the following six equations

$$\frac{mc^2}{q}\partial_{[\mu}u_{\nu]}+F_{\mu\nu}=s_{\mu\nu}\,. \tag{2.7}$$

Introducing the generalized 4-momentum of the "superelectron"

$$P_{\mu}=mcu_{\mu}+\frac{q}{c}A_{\mu}\,. \tag{2.8}$$

Eq.(2.2) takes the form:

$$\eta^{\nu\mu\rho\sigma}\nabla_{[\rho}P_{\sigma]}=-\frac{2q}{c}sD^{\mu\nu}\,. \tag{2.9}$$

These equations may be regarded as the generalization of the covariant London equations for a type II superconductor [2].

3. *Anholonomic formulation.* Let us assume that in the domain of space-time occupied by the superconductor we have a field of tetrads of mutually orthogonal unit vectors $\vec{e}_{\underline{\alpha}}$, where $\vec{e}_{\underline{0}}$ timelike and future-pointing and $\vec{e}_{\underline{i}}$ spacelike. The conditions of orthonormality may be written [3]

$$e^{\sigma}_{\underline{\alpha}}e_{\underline{\beta}\sigma}=\eta_{\underline{\alpha\beta}}\,, \tag{3.1}$$

where

$$\eta_{\underline{\alpha\beta}}=\eta^{\underline{\alpha\beta}}=\mathrm{diag}(+1,-1,-1,-1)$$

satisfies

$$\eta^{\underline{\alpha\beta}}\eta_{\underline{\sigma\beta}}=\delta^{\alpha}_{\sigma}\,. \tag{3.2}$$

The tetrad or Lorentz indices being raised or lowered by means of the η matrix, this permits to define the reciprocal system

$$e^{\underline{\alpha}\sigma}=\eta^{\underline{\alpha\beta}}e^{\sigma}_{\underline{\beta}}\,,\quad e^{\underline{\alpha}}_{\sigma}=\eta^{\underline{\alpha\beta}}e_{\underline{\beta}\sigma} \tag{3.3a}$$

with

$$e^{\sigma}_{\underline{\alpha}}e^{\underline{\beta}}_{\sigma}=\delta^{\beta}_{\alpha}\,,\quad e^{\sigma}_{\underline{\alpha}}e^{\underline{\alpha}}_{\rho}=\delta^{\sigma}_{\rho}\,. \tag{3.3b}$$

Any tensor $F^{\mu\nu}$ or vector A^{μ} defined at a given point may be resolved into its invariant components along the vectors $e^{\sigma}_{\underline{\alpha}}$

$$F^{\mu\nu}=e^{\mu}_{\underline{\alpha}}e^{\nu}_{\underline{\beta}}F^{\underline{\alpha\beta}}\,,\quad A^{\mu}=e^{\mu}_{\underline{\sigma}}A^{\underline{\sigma}} \tag{3.4a}$$

from which it follows

$$F^{\underline{\alpha\beta}}=e^{\underline{\alpha}}_{\mu}e^{\underline{\beta}}_{\nu}F^{\mu\nu}\,,\quad A^{\underline{\alpha}}=e^{\underline{\alpha}}_{\mu}A^{\mu}\,. \tag{3.4b}$$

The invariants $F^{\underline{\alpha\beta}}$, $A^{\underline{\alpha}}$ are the physical components of the corresponding tensor and vector fields for the observer with 4-velocity $e^{\sigma}_{\underline{0}}$ using the reference frame defined by the orthonormal triad $\{e_{\underline{i}}^{\sigma}\}$.

Using (3.3) and (3.4) the anholonomic form of London's equations (2.7) with respect to an orthonormal tetrad (OT) $\{\vec{e}_{\underline{\alpha}}\}$ may be exhibited in the form

$$mc\left(\partial_{\underline{\mu}} u_{\underline{\nu}} - \partial_{\underline{\nu}} u_{\underline{\mu}} - u_{\underline{\sigma}} C^{\underline{\sigma}}_{\underline{\nu\mu}}\right) + \frac{q}{c} F_{\underline{\mu\nu}} = \frac{q}{c} s_{\underline{\mu\nu}} \tag{3.5}$$

with

$$C^{\underline{\sigma}}_{\underline{\nu\mu}} = e^{\alpha}_{\underline{\nu}} e^{\beta}_{\underline{\mu}}\, \partial_{[\alpha}\, e^{\underline{\sigma}}_{\beta]}\,. \tag{3.6}$$

This geometrical object is called by Schouten the object of anholonomity [5]. The tetrad components $F^{\underline{\mu\nu}}$ of the electromagnetic field tensor are connected to the components $A_{\underline{\mu}}$ of the 4-potential by a relation, which differs from the corresponding holonomic relation in special relativity by the presence of a correction term with C

$$F^{\underline{\mu\nu}} = \partial_{\underline{\mu}} A_{\underline{\nu}} - \partial_{\underline{\nu}} A_{\underline{\mu}} - C^{\underline{\sigma}}_{\underline{\nu\mu}} A_{\underline{\sigma}}\,. \tag{3.7}$$

The information on the gravitational fields is conveyed by the components of C. Introducing the operator of covariant derivation with respect to the OT $\{\vec{e}_{\underline{\alpha}}\}$, Eq. (3.5) read

$$mc\,\nabla_{[\underline{\mu}}\, u_{\underline{\nu}]} + \frac{q}{c} F_{\underline{\mu\nu}} = \frac{q}{c} s_{\underline{\mu\nu}}\,, \tag{3.8}$$

where

$$\nabla_{\underline{\mu}} u_{\underline{\nu}} = \partial_{\underline{\mu}} u_{\underline{\nu}} - \Gamma^{\underline{\sigma}}_{\underline{\nu\mu}} u_{\underline{\sigma}}\,. \tag{3.9}$$

The $\Gamma^{\underline{\sigma}}_{\underline{\nu\mu}}$ are the so-called Ricci rotation coefficients and

$$C^{\underline{\sigma}}_{\underline{\nu\mu}} = \Gamma^{\underline{\sigma}}_{\underline{\nu\mu}} - \Gamma^{\underline{\sigma}}_{\underline{\mu\nu}}\,. \tag{3.10}$$

Once the C's are known, the Γ's obtained with the aid of the formula

$$\Gamma^{\underline{\sigma}}_{\underline{\beta\lambda}} = \frac{1}{2}\left(C^{\underline{\sigma}}_{\underline{\beta\lambda}} - \eta^{\underline{\alpha\sigma}}\eta_{\underline{\beta\rho}}\, C^{\underline{\rho}}_{\underline{\alpha\lambda}} - \eta^{\underline{\alpha\sigma}}\eta_{\underline{\lambda\rho}}\, C^{\underline{\rho}}_{\underline{\alpha\beta}}\right). \tag{3.11}$$

We shall now use Eq.(3.5) to investigate the electromagnetic fields generate by vortices and gravitational field in a type II superconductor. We assume a stationary universe with metric of the form

$$dS^2 = g_{ij}dx^i dx^j + g_{00}\left(dx^0\right)^2\,, \tag{3.12}$$

where the g's are independent of the time coordinates x^0. In this universe we have a type II superconductor with world lines of the normal part along the x^0-lines: consequently

$$w^i(n) = 0\,, \quad g_{00}\left(w^0(n)\right)^2 = 1\,, \quad W^0(n) = \frac{1}{\sqrt{g_{00}}}\,. \tag{3.13}$$

For our purpose, the most suitable OT is one adapted to the stationary character of space time, the component $\vec{e}_{\underline{0}}$ pointing along the timelike. Killing vector ξ, this choice is equivalent to identify $\vec{e}_{\underline{0}}$ with the unit 4-velocity $\vec{w}$ of the normal part. With respect to the adapted system of local coordinate $\{x^\alpha\}$ the components of the vector ξ and its square satisfy

$$\xi^0 = 1, \quad \xi^i = 0, \quad \xi^2 = g_{\alpha\beta}\,\xi^\alpha\xi^\beta = g_{00} > 0, \quad \left(\xi = \sqrt{\xi^2} > 0\right). \tag{3.14}$$

Such a tetrad field has been obtained in ref. [6]. The OT $\vec{e}_{\underline{\alpha}}$ and natural frame $\vec{e}_\alpha$ are related by the formulae

$$\vec{e}_{\underline{0}} = \frac{1}{\xi}\vec{e}_0, \quad \vec{e}_0 = \xi\,\vec{e}_{\underline{0}}, \quad \vec{e}_{\underline{i}} = -\varphi_{\underline{i}}\,\vec{e}_0 + e_{\underline{i}}^j\vec{e}_j, \quad \vec{e}_i = \xi\varphi_i\,\vec{e}_{\underline{0}} + e_i^{\underline{j}}\vec{e}_{\underline{j}}, \tag{3.15}$$

where φ_λ and $\varphi_{\underline{i}}$ are respectively defined by

$$\varphi_\lambda = \frac{\xi_\lambda}{\xi^2} = \frac{g_{0\lambda}}{\xi^2}\,(\varphi_0 = 1), \quad \varphi_{\underline{i}} = e_{\underline{i}}^j\,\varphi_j. \tag{3.16}$$

The components $C_{\underline{\mu\nu}}^{\underline{\alpha}}$ with respect to the OT $\{\vec{e}_{\underline{\alpha}}\}$ as given by (3.15) may be obtained by performing the calculation indicated by (3.6). The components of C may be expressed in terms of the corresponding component of the object $\dot{C}$ defined on the 3-space with quadratic form

$$d\dot{S}^2 = \dot{g}_{ik}dx^i dx^k, \quad \dot{g}_{ik} = g_{ik} - \frac{g_{0i}g_{0k}}{g_{00}} \tag{3.17}$$

corresponding to the spatial part of the square interval (3.12). The results are [1,6]

$$C_{\underline{jk}}^{\underline{i}} = e_{\underline{j}}^m e_{\underline{k}}^l\,\delta_{[m}\,e_{l]}^{\underline{i}} \equiv \dot{C}_{\underline{jk}}^{\underline{i}}, \quad C_{\underline{j0}}^{\underline{i}} = 0, \quad C_{\underline{i0}}^{\underline{0}} = \frac{\partial_{\underline{i}}\xi}{\xi}, \quad C_{\underline{ij}}^{\underline{0}} = \xi\dot{\nabla}_{[\underline{i}}\varphi_{\underline{j}]}, \tag{3.18}$$

where $\dot{\nabla}_i$ is the operator of covariant derivative related to the metric tensor $\dot{g}_{ij}$.

Let us consider the immediate consequences of the above anholonomic formulation. The substitutions $(\mu = 0,\ \nu = i)$ and $(\mu = i,\ \nu = j)$ in Eq. (3.5) give respectively

$$mc\,\partial_{[\underline{0}}\,u_{\underline{i}]} + \frac{q}{c}F_{\underline{0i}} - mcu_{\underline{0}}C_{\underline{i0}}^{\underline{0}} - \frac{q}{c}s_{\underline{0i}} = 0, \tag{3.19}$$

$$mc\,\partial_{[\underline{i}}\,u_{\underline{j}]} + \frac{q}{c}F_{\underline{ij}} - mc\left(u_0 C_{\underline{ji}}^{\underline{0}} - u_{\underline{k}}C_{\underline{ji}}^{\underline{k}}\right) - \frac{q}{c}s_{\underline{ij}} = 0. \tag{3.20}$$

We recall that the components $u^{\underline{i}} = e_\alpha^{\underline{i}}\left(dx^\alpha/dS\right)$ are the space components of the 4-velocity $u^{\underline{\alpha}}$ of the superparticle in the direction of the spatial component $e_{\underline{i}}^\mu$ of the OT $\{\vec{e}_{\underline{\alpha}}\}$ as measured by an observer with 4-velocity $e_{\underline{0}}^\mu = w^\mu(n)$, i.e. at rest with respect to the normal part and dS is the element of proper time measured by an observer moving with the superparticle. The component $u_{\underline{0}} = u^{\underline{0}} = e_\alpha^{\underline{0}}\left(dx^\alpha/dS\right)$ may be expressed in the form

$u^{\underline{0}} = (ds_n/ds)$, where ds_n is the element of proper time as measured by an observer at the rest with respect to the normal part.

Since there is no current inside a superconductor at rest, i.e. when $w^\alpha(n)$ satisfies condition (3.13), the space components $u^{\underline{i}}$ of the physical velocity $u^{\underline{\alpha}}$ of the superparticle must be set equal zero. Introducing the physical electric and magnetic fields as measured by an observer with 4-velocity $e^\alpha_{\underline{0}} = w^\alpha(n)$ with the aid of the invariants

$$\underset{i}{E} = F_{\underline{0i}} = -F^{\underline{0i}}, \quad \underset{k}{H} = \frac{1}{2}\varepsilon_{kij} F_{\underline{ij}}. \tag{3.21}$$

Using (3.21) and (3.18), Eqs. (3.19) and (3.20) may be exhibited in the form:

$$\underset{i}{E} = \frac{mc^2}{q}\frac{1}{\xi}\partial_{\underline{i}}\xi + \frac{1}{2}s\,\varepsilon_{\underline{0ijk}} D^{j\underline{k}}, \quad D^{\underline{jk}} = -u^{\underline{j}}(L)v^{\underline{k}}(L) + u^{\underline{k}} v^{\underline{j}}(L), \tag{3.22}$$

$$\varepsilon_{kij}\underset{k}{H} = \frac{mc^2}{q}\xi\dot{\nabla}_{[\underline{i}}\varphi_{\underline{j}]} - s\,\varepsilon_{\underline{0ijk}} D^{\underline{0k}}. \tag{3.23}$$

If $\bar{e}_{\underline{3}}$ points along the axis of symmetry of the problem under consideration, the magnetic field is directed along $\bar{e}_{\underline{3}}$ and $v(L) = \bar{e}_{\underline{3}}$. Then according to (3.22) and (3.23) we have the following expression for the electric and magnetic fields generated inside the superconductor

$$\underset{3}{H} = \frac{mc^2}{q}\dot{\nabla}_{[1}\varphi_{2]} + u^{\underline{0}}(L)s, \quad u^{\underline{0}}(L) = \frac{dS_n}{dS}, \tag{3.24}$$

$$\underset{i}{E} = \frac{mc^2}{q}\frac{\partial_i\xi}{\xi} - s\,\varepsilon_{ij3}u^{\underline{j}}. \tag{3.25}$$

Eqs.(3.24) and (3.25) show that both the inhomogeneous gravitational field and the vortices do contribute to the generation of an electromagnetic field inside a type II superconductor in a stationary universe.

4. *Newtonian approach*. In this section adopting London's approximation we derive the basic equations of type II superconductor [4]. We consider free particles of charge q ($q < 0$) and mass m, moving without friction. Assuming that the charged particles form a nonviscous fluid with velocity field $v(x, y, z, t)$, besides the action of the electromagnetic field we have to take into account the reaction of the Magnus force on the particle. In this case, as it is customary in hydrodynamics the nonrelativistic Newtonian equations of motion may be written in the following form

$$\frac{d\bar{v}}{dt} = \frac{\partial\bar{v}}{\partial t} + (\bar{v}\bar{\nabla})\bar{v} = \frac{q}{m}\left(\bar{E} + \frac{\bar{v}\times\bar{B}}{c}\right) - \frac{q\Phi_0}{mc}n(L)\bar{v}\times\bar{\chi} + \frac{q\Phi_0\,n(L)}{mc}\bar{v}(L)\times\bar{\chi}, \tag{4.1}$$

where Φ_0 is the vortex magnetic flux, $\bar{v}$ the velocity of the particle (q, m) and $n(L)$, $\bar{v}(L)$ are respectively the number density and velocity of vortices.

$\bar{\chi}$ is the unit vector along vortex direction. Using the well known vector formula

$$(\bar{\upsilon}\bar{\nabla})\bar{\upsilon} = \bar{\nabla}\frac{\upsilon^2}{2} - \bar{\upsilon}\times(\bar{\nabla}\times\bar{\upsilon}),$$

the equations of motion for the velocity field in the presence of vortices are

$$\frac{\partial\bar{\upsilon}}{\partial t} + \bar{\nabla}\left(\frac{\upsilon^2}{2}\right) - \frac{q\Phi_0}{mc}n(L)\bar{\upsilon}\times\bar{\chi} - \frac{q}{m}\bar{E} = \bar{\upsilon}\times\left(\bar{\nabla}\times\bar{\upsilon} + \frac{q\bar{B}}{mc} - \frac{q\Phi_0}{mc}n(L)\bar{\chi}\right). \quad (4.2)$$

By taking the curl of both sides and using the conservation law of vortices

$$\frac{\partial n(L)}{\partial t} + \bar{\nabla}(n(L)\bar{\upsilon}(L)) = 0 \quad (4.3)$$

and Maxwell's equation

$$\bar{\nabla}\times\bar{E} = -\frac{1}{c}\frac{\partial\bar{B}}{\partial t} \quad (4.4)$$

we obtain

$$\frac{\partial\bar{w}}{\partial t} = \bar{\nabla}\times(\bar{\upsilon}\times\bar{w}), \quad (4.5)$$

where

$$\bar{w} = \bar{\nabla}\times\bar{\upsilon} + \frac{q\bar{B}}{mc} - \frac{q\Phi_0}{mc}n(L)\bar{\chi}. \quad (4.6)$$

The quantity $\bar{w}$ as defined in (4.6) differs from the corresponding $\bar{w}$ introduced by London [4] by a correction term due to the magnetic field of vortices. An important consequence of Eq. (4.5) is the following property: if at $t=0$ the initial state is $\bar{w}=0$, it follows that $\bar{w}=0$ for all values of t, accordingly we have

$$\bar{w} = \bar{\nabla}\times\bar{\upsilon} + \frac{q\bar{B}}{mc} - \frac{q\Phi_0}{mc}n(L)\bar{\chi} = 0. \quad (4.7)$$

Substitution of Eq.(4.7) in Eq. (4.2) gives

$$\frac{\partial\bar{\upsilon}}{\partial t} + \bar{\nabla}\left(\frac{\upsilon^2}{2}\right) - \frac{q}{m}\bar{E} - \frac{q\Phi_0}{mc}n(L)\bar{\upsilon}(L)\bar{\chi} = 0. \quad (4.8)$$

Following London the particular solutions (4.7) and (4.8) account for the Meisner effect and may be regarded as the basic equations for type II superconductors.

Let us now suppose that $\partial\bar{\upsilon}/\partial t = 0$ and $\bar{j} = 0$, neglecting the quadratic term in velocity, Eqs.(4.7) and (4.8) yields the expressions for the magnetic and electric fields:

$$\bar{B} = \Phi_0 n(L)\bar{\chi}, \quad (4.9)$$

$$\bar{E} = -\frac{\bar{v} \times \bar{B}}{c}. \tag{4.10}$$

As expected, the magnetic field is a pure vortex field whereas the generation of the electric field results from the motion of vortices with respect to the normal part. Let us note that the mechanism at origin of the electric field is the unipolar induction of the magnetic field of vortices. The above Newtonian results are in agreement with the Newtonian approximation of expressions (3.24) and (3.25) valid in stationary universe.

5. *Conclusion.* The basic equations of type II superconductors have been obtained by adopting London's phenomenological approach. The generation of the electromagnetic field in a superconductor at rest in a stationary universe has been investigated using the method of anholonomic frames. The Newtonian formulation of the problem has also been studied. As a concluding remark we shall mention that the expressions for the electric and magnetic fields we have derived may be applied to the investigation of certain aspects of the electrodynamics of pulsars. As it is well known, in the core of neutron stars the magnetic field lines coincide with the vortex lines of the proton "fluid", which is considered as a superconductor. From the obtained expression we see that the electric field generated in the core of a neutron star is proportional the angular velocity Ω_s of the neutron-proton superfluid. This result differs from the well known assertion that the electric field is proportional to the angular velocity Ω_n of the crust, i.e. the normal part. Since in certain situations in the life of a pulsar the inequality $\Omega_s \gg \Omega_n$ is realized the electric field intensity computed from our formula will be larger than the corresponding predictions of Goldreich and Julian [7].

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ТЕТРАДНАЯ ФОРМУЛИРОВКА ОСНОВНЫХ УРАВНЕНИЙ СВЕРХПРОВОДНИКОВ II РОДА В ИСКРИВЛЕННОМ ПРОСТРАНСТВЕ

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Получены основные уравнения сверхпроводников II рода в феноменологическом приближении Лондона. Генерация электромагнитного поля в покоящемся в стационарной Вселенной сверхпроводнике изучено в рамках метода неголономных систем отсчета. Рассмотрена также ньютоновская формулировка задачи.

Ключевые слова: *сверхпроводники: основные уравнения*

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