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GUN-TYPE EFFECTS IN A GENERALIZED MAXWELL FIELD

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In această lucrare se studiază numeric, în aproximaţia fractală a mişcării, interacţiunea particule încărcate electric - undele electromagnetice generalizate (gravitaţionale şi electromagnetice) – câmp magnetic generalizat, constant. Se pun în evidenţă secvenţe distincte ale mişcării: regulată, fractală, effecte de tip gun, effecte de tip gun haotic şi efecte de tip gun-multiplu. Se fac unele consideraţii asupra secvenţelor de mişcare observate.

In the fractal approximation of motion, by means of numerical simulation, the interaction charged particle-generalized electromagnetic waves (gravitational and electromagnetic waves)-generalized constant magnetic field is studied. Some distinct sequences of the movement are emphasized: regular motion, motion fractalization, gun-type effect, chaotic gun-type effect and multi-gun-type effect. Several considerations of these movement sequences are analyzed.

Keywords: gun-type effect, fractals, generalized Maxwell field

1. Introduction

In recent papers [1-4] the motion of a charged particle in a field of a transverse monochromatic electromagnetic wave and within a constant external magnetic field was studied. New phenomena (gun effect, chaotic gun effect, etc.)

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are observed if the amplitude of the wave is sufficiently large. It is shown that a high acceleration of charged particles is obtained by a cascade of gun effects which lead to sudden jumps between phase Larmor circles. Numerical experiments display a clear energy dependence of the time of escape of particles as they exit from the acceleration region. This result appears important for laboratory and space research experiments on particle acceleration.

Due to the fact that the different movement sequences presented in [1-4] refer only to one type of interaction scale (*i.e.* the atomic scale), the need to generalize this motion to any scale of interaction becomes essential. We can make this possible by using the fractal space-time theory [5-7]. In such a context, the particles motions take place on continuous but non-differentiable curves (fractal curves). We shall name this approach “the fractal approximation of motion” and some of its implications are given in [8-11].

In the present paper, we shall study the interaction charged particle-generalized electromagnetic waves (gravitational and electromagnetic waves)-generalized constant magnetic field, in the fractal approximation of motion. In such conjecture, different scales of interaction (e.g. atomic scale, planetary scale, galactic scale) can be analyzed. Our results generalize the ones in [1].

2. A short reminder on the generalized Maxwell equations

Based on results from [3, 12], in the case when four-dimensional space-time is split into space plus time (3+1), the electromagnetic field $F^{\alpha\beta}$ breaks up into two parts: the electric field $\mathbf{g}_e$ and the magnetic field $\mathbf{B}_e$. These fields verify Maxwell’s equations:

$$\nabla \cdot \mathbf{g}_e = \frac{\rho_e}{\varepsilon_0} \tag{1}$$

$$\nabla \cdot \mathbf{B}_e = 0 \tag{2}$$

$$\nabla \times \mathbf{g}_e = -\frac{\partial \mathbf{B}_e}{\partial t} \tag{3}$$

$$\nabla \times \mathbf{B}_e = \mu_0 \mathbf{j}_e + c^{-2} \frac{\partial \mathbf{g}_e}{\partial t} \tag{4}$$

where $\mathbf{j}_e$ is the electric current density vector $\mathbf{j}_e = \rho_e \mathbf{v}$, ρ_e the electric charge density, μ_0 the vacuum magnetic permeability and c the speed of light in vacuum.

Likewise, the general relativistic gravitational field ($g^{\alpha\beta}$) breaks into three parts [13]: (i) an electric like part, g^{00}, whose gradient for weak gravity is

Newtonian acceleration $\mathbf{g}_g$; (ii) a magnetic part, g^{0i} , whose curl for weak gravity is the gravitomagnetic field $\mathbf{B}_g$; (iii) a spatial metric, g^{ij} , whose curvature tensor is the 'curvature of space'.

In the weak gravitational field, the tensor metric $g_{\mu\nu}$ becomes [13]:

$$g_{\mu\nu} \approx \eta_{\mu\nu} + h_{\mu\nu} = \eta_{\mu\nu} + \bar{h}_{\mu\nu} - \frac{1}{2}\eta_{\mu\nu}\bar{h} \tag{5}$$

where $\eta_{\mu\nu} = (+,-1,-1,-1)$ is the usual Minkovski metric, $h_{\mu\nu}$ is to be treated as a small perturbation to $\eta_{\mu\nu}$, and

$$h_{\mu\nu} = \bar{h}_{\mu\nu} - \frac{1}{2}\eta_{\mu\nu}\bar{h}\,, \quad \bar{h} = h^{\alpha}_{\alpha}\,,\ \mu,\nu,\alpha = 0,1,2,3 \qquad \text{(6 a-c)}$$

Then, the general relativistic equations:

$$G^{\mu\nu\lambda}_{\lambda} = -\frac{8\pi G}{c^4} T^{\mu\nu} \tag{7}$$

where G is Newton's constant, c is the speed of light in vacuum, $G^{\mu\nu\lambda}$ is the Einstein's tensor and $T^{\mu\nu}$ is the energy-momentum tensor that is the source of the gravitational field, through the substitutions [13]

$$\begin{gathered} \mathbf{g}_g = \left(g^1_g, g^2_g, g^3_g\right),\ \ g^i_g = G^{00i}\ (i = 1,2,3)\,, \\ \mathbf{A}_g = \left(A^1_g, A^2_g, A^3_g\right), A^i_g = \frac{1}{4}h^{0i}\,, \\ \mathbf{B}_g = \left(B^1_g, B^2_g, B^3_g\right),\ \ B^1_g = G^{023},\ B^2_g = G^{031}, B^3_g = G^{012}\,. \\ G^{0ij} = A^{i,j}_g - A^{j,i}_g\,, \mathbf{B}_g = \nabla\times\mathbf{A}_g \end{gathered} \qquad \text{(8a-j)}$$

imply the Maxwell-type gravitational equations [13, 14]:

$$\nabla\cdot\mathbf{g}_g = -4\pi G\rho \tag{9}$$

$$\nabla\cdot\mathbf{B}_g = 0 \tag{10}$$

$$\nabla\times\mathbf{g}_g = -\frac{\partial\mathbf{B}_g}{\partial t} \tag{11}$$

$$\nabla\times\mathbf{B}_g = -\frac{4\pi G}{c^2}\mathbf{j} + \frac{1}{c^2}\frac{\partial\mathbf{g}_g}{\partial t} \tag{12}$$

In relation (12) $\mathbf{j}$ is the mass current density vector, $\mathbf{j} = \rho\mathbf{v}$, and ρ the mass density.

Now, if in a space-time manifold, equations (1)-(4) as well as equations (9)-(12) are valid, based on the superposition principle [15], we can introduce the generalized fields:

$$\mathbf{g} = \mathbf{g}_g + \frac{q}{m}\mathbf{g}_e, \quad \mathbf{B} = \mathbf{B}_g + \frac{q}{m}\mathbf{B}_e \tag{13}$$

These fields verify the generalized Maxwell's equations [15]

$$\nabla \cdot \mathbf{g} = \left(-4\pi G + \frac{1}{\varepsilon_0}\frac{q^2}{m^2}\right)\rho \tag{14}$$

$$\nabla \cdot \mathbf{B} = 0 \tag{15}$$

$$\nabla \times \mathbf{g} = -\frac{\partial \mathbf{B}}{\partial t} \tag{16}$$

$$\nabla \times \mathbf{B} = \left(-\frac{4\pi G}{c^2} + \mu_0 \frac{q^2}{m^2}\right)\mathbf{j} + \frac{1}{c^2}\frac{\partial \mathbf{g}}{\partial t} \tag{17}$$

where we accounted for the following relations:

$$q_e = \frac{q}{m}\rho, \; j_e = \frac{q}{m} j\,. \tag{18}$$

As an example, equation (14) is obtained adding equation (1) multiplied by q/m to equation (9) and taking into account the first relations from the equations (13) and (18), respectively.

3. Transitions between levels at different scales of interaction by means of the fractal approximation of motion

The transition of a particle (with charge) from a given level to another one of higher energy implies, in our opinion, the presence of a universal acceleration mechanism (e.g., the acceleration of a charged particle by a stochastic medium – stochastic acceleration [16, 17]).

Usually, the stochastic acceleration can be modeled by the triplet: charged particle – homogenous magnetic field – polarized or non-polarized electro-magnetic field (for details see [1-4, 15, 16]). The associated mechanical models [17], for example "vibrating balls in a gravitational field", are operating both with an accelerating force (vibration is associated to the electromagnetic wave), and with a returning force (the gravitational force is associated with the Lorentz force).

Now, once accepted the "functionality" of the stochastic acceleration mechanism at both atomic and planetary scales, in the mathematical modeling the following situations can be distinguished:

a) particle – homogenous generalized magnetic field – non-polarized generalized electromagnetic wave;

b) particle – homogenous generalized magnetic field – linear polarized generalized electromagnetic wave. Particularly, we can choose a static generalized magnetic field whose vector points in the *z* direction, $\boldsymbol{B} = B_0 \hat{z}$, and a generalized electromagnetic wave propagating along the *x* direction, its polarization being on the *y* direction [2],

$$\begin{pmatrix} \boldsymbol{g} \\ \boldsymbol{B} \end{pmatrix} = \begin{pmatrix} g_0 \hat{y} \\ H_0 \hat{z} \end{pmatrix} \cos\left(kx - \omega t\right) \tag{19}$$

It is more convenient to describe this "composite" field in terms of the generalized vector potential

$$\boldsymbol{A} = \left[B_0 z + A_{\perp} \sin\left(kx - \omega t\right)\right]\hat{\boldsymbol{e}}_y \tag{20}$$

c) particle – homogenous generalized magnetic field on *Oz* direction – circular polarized generalized electromagnetic wave.

For all these cases, a specific generalized electrodynamics based on generalized Maxwell equations and relativistic equation of motion in a generalized Maxwell field will be developed.

For the cases a) and b), the previously mentioned equations, in the fractal dimensionless variable

$$T = \frac{c^2}{D}t,\ X = \frac{c}{D}x,\ \boldsymbol{P} = \frac{\boldsymbol{p}}{m_0 c},\ \Omega_B = \frac{D}{c^2}\omega_B = \frac{\gamma D}{c^2}\omega_c = \gamma\Omega_c$$
$$\gamma = \left(1 + P_x^2 + P_y^2\right)^{1/2},\ \beta = \frac{H}{\Omega_B} = \frac{\Omega_{wave}}{\Omega_B} = \frac{D}{c^2}\frac{qH_0}{m_0\Omega_B},\ \varepsilon = \frac{qA_{\perp}}{m_0 c} \tag{21a-g}$$

and following the procedure from [1-3, 17], implies the equation system

$$\frac{dX}{dt} = \frac{1}{\gamma}P_x = \frac{P_x}{\sqrt{1 + P_x^2 + P_y^2}}$$
$$\frac{dP_x}{dt} = \Omega_c\left[\beta\cos\left(X - T\right) + 1\right]P_y \tag{22a-c}$$

$$\frac{dP_y}{dt} = -\Omega_c\left[\beta\cos(X-T)+1\right]P_x + H\cos(X-T)$$

In the previous c) case, following the same procedure as in a) and b) cases, it results the equation system,

$$\frac{dX}{dt} = \frac{1}{\gamma}P_x = \frac{P_x}{\sqrt{1+P_x^2+P_y^2}}$$

$$\frac{dP_x}{dt} = -\gamma\left[H\cos(X-T)+\omega_c\right]P_y \qquad (23a\text{-}c)$$

$$\frac{dP_y}{dt} = -\gamma\left[H\sin(X-T)+\Omega_c\right]P_x + H\cos(X-T)$$

Due to their non-linearity, analytical solutions for the systems (22a-c) and (23a-c) are difficult to be obtained. This is why we will numerically integrate them (examples in this sense are specified in [18-20]).

The numerical solutions of the equations (23a-c) and their correspondences with the dynamics of the system are obtained using the Mathematica 7.0 software with an adaptive step-size control [17].

We initiate the numerical calculus for the following values of parameters

$$\Omega_B = 0.5,\ n = 4,\ \gamma_0 \equiv \gamma_4 = 2 \qquad (24a\text{-}c)$$

The dynamic of equations generates a flow in a 3-dimensional (3D) phase-space, (P_x, P_y, X). The initial values were

$$\left[T, P_x, P_y, X\right] \equiv \left[0.001, \sqrt{1.5}, \sqrt{1.5}, 0.001\right] \qquad (25)$$

Let us note that, for the values (24a-c) and (25), the chaotic character of the movements becomes evident.

As may be expected, the particle motion for small dimensionless amplitudes of the external electromagnetic wave (e.g. $H = 0.03$) remains regular and no acceleration arises. If the amplitude is increased to $H = 0.13$, the particle motion becomes more complex but retains a regular character. The onset of a fractalization (stochastization) is observed once H exceeds 1.3 but the energy gain remains initially still small.

When $H \geq 1.6$ there emerges a strong acceleration and a gun-type effect is initiated, whereby a sudden expulsion of a particle from the system takes place in a certain direction. The gain in energy becomes significant and thus a state of a resonance overlap is obtained.

A major chaotic gun-type effect erupts for $H \geq 2.3$. In such case, we distinguish three elements of movement: first, a localized chaotic regime emerges, a high frequency oscillation with chaotic modulation of the amplitude appears, and finally we observe the sharp rectilinear part of the trajectory which in fact displays the gun-type effect.

A very interesting result arises if we increase the number of iterations and the duration of the operation (see Fig. 1). We note that in the process of acceleration the energy is increased by 'quantum jumps' so that a charged particle gains energy within a multi-gun-type effect. The jump from a 'spiral Larmor orbit' to another one is performed by a gun-type effect. The radii of the Larmor circles and the corresponding energy of the particle increase.

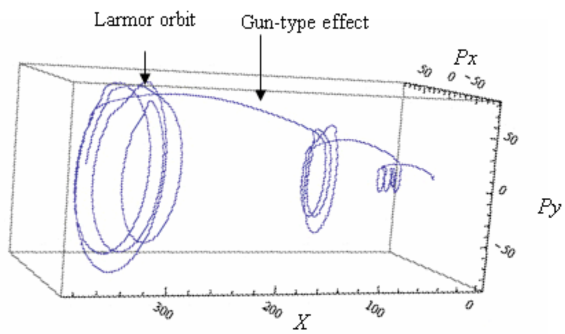

Fig. 1. Numerical solution of the system (23a-c) for $H = 2.3$ and $T = 0 - 5300$. A multi-gun type effect and Larmor orbits

The existence of a multi-gun-type effect via different Larmor orbits is illustrated clearly by the time series for P_x (Fig. 2), and also through the Poincaré sections (Fig. 3). In Fig. 2 the inclined lines display the chaotic gun-type effects between different Larmor orbits represented here by vertical oscillations. From the $(P_x T)$ time series (Fig. 2) we deduce that, during a gun-type regime, the 'longitudinal momentum' (P_x) increases and represents the highest value which may be achieved in the current Larmor spiral. The highest value is transferred to the following Larmor spiral in which the particle absorbs again energy from the electromagnetic field until a new gun-type effect erupts. In fact, on a specific Larmor spiral the particle will go around repeatedly, receiving a kick of energy each time it completes an orbit.

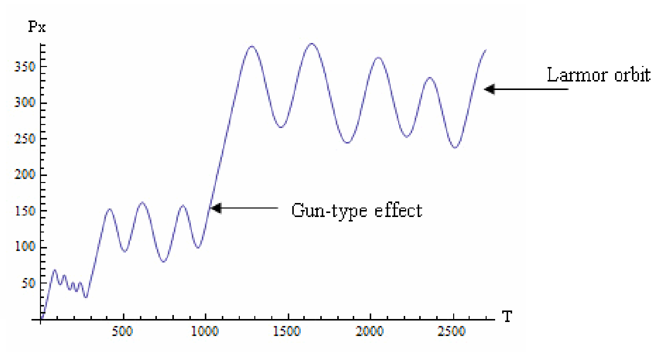

Fig. 2. (P_x, T) time-series corresponding to the dynamic system (23a-c) for the case of a multi-gun type effect illustrated in Fig. 1.

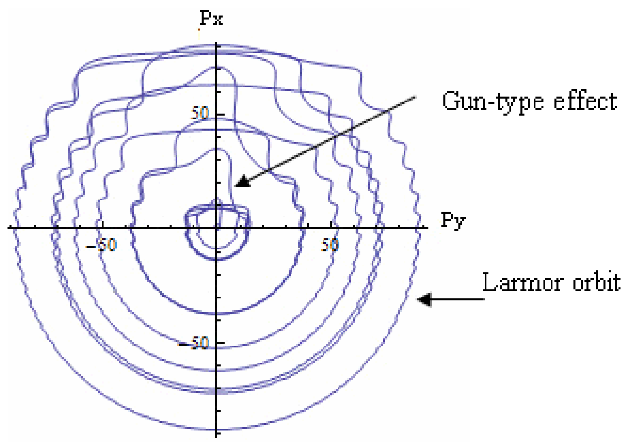

Fig. 3. Projection (phase particle or orbit) on the (P_x, P_y) phase-space of the particle trajectory shown in Fig.1

In a phase-portrait (P_x, P_y) (Fig. 3) the motion seems apparently regular, but a sharp sight can distinguish the jump from a Larmor circle to the next one, as generated by a chaotic gun-type effect. All vertical lines display in fact a gun-type effect.

4. Conclusions

A specific electrodynamics is “simulated” through fractal “medium” property, electrodynamics described by the generalized Maxwell’s equations coupled with a charged particle equation of relativistic motion. In such conjecture the transitions between levels at different scales of interaction are induced by means of a multi-gun type effect via different Larmor orbits.

If we neglect the gravitational effect as against the electromagnetic field, we can study transitions between levels at atomic scale. Moreover, if we neglect the electromagnetic effect as against the gravitational field, we can study transitions between levels at planetary scale. In such approach it becomes easy to interpret the orbital “dance” of Saturn’s satellites Janus and Epimetheus [21].

The same considerations can be extended to galactic motions in order to interpret the Tifft effect [22].

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