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ELEMENTARY PARTICLE PHYSICS AND FIELD THEORY

QUANTUM DYNAMICS OF BIOLOGICAL SYSTEMS AND DUST PLASMA NANOPARTICLES

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A quantum solution of the Fisher–Kolmogorov–Petrovskii–Piskunov equation with convection and linear diffusion is obtained which can provide the basis for the quantum biology and quantum microphysics equation. On this basis, quantum emission of biological systems, separate microorganisms (cells or bacteria), and dust plasma particles is investigated.

Keywords: quantum solution of convection–diffusion equation, quantum biology, quantum microphysics, dust plasma.

INTRODUCTION

It is well known that the basic equation describing the dynamics of a colony of bacteria or cells is the Fisher–Kolmogorov–Petrovskii–Piskunov (FKPP) equation whose kinetics is determined by local nonlinear terms and diffusion causes spatial distribution of population [1, 2]. In the FKPP model, a number of factors influencing the dynamics of biological systems the allowance of which leads to nonlocal generalization of the FKPP equation are disregarded. Different numerical methods of generalization of the FKPP equation were studied in [3–6].

In the present study, the quantum dynamics of biological systems, individual microorganisms, and dust plasma particles is analytically investigated based on the local FKPP equation with convection and linear diffusion.

1. QUANTUM SOLUTION OF THE FKPP LOCAL EQUATION WITH CONVECTION AND LINEAR DIFFUSION

The one-dimensional generalized Fisher–Kolmogorov–Petrovskii–Piskunov equation describing the dynamics of the population density of microorganisms has the form [1, 2]

$$\frac{\partial u(x,t)}{\partial t} = [D+\eta u(x,t)]\frac{\partial^2 u(x,t)}{\partial x^2} + \gamma u(x,t) + \frac{\partial V(x)}{\partial x}u(x,t) - qu(x,t)\int_{-\infty}^{\infty} b(x,z)u(z,t)\,dz\,. \tag{1}$$

Here the kinetic variable $u(x,t)$ is the mass density, D is the constant diffusion coefficient, η is the nonlinear diffusion parameter, γ characterizes the rate of $u(x,t)$ increase, $V(x)$ is the convective velocity, and the competitive

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losses are described by the integral expression $qu(x,t)\int\limits_{-\infty}^{\infty} b(x,z)u(z,t)\,dz$ quadratic in the density with the influence function $b(x,z)$ and the nonlinearity parameter q.

We now choose the parameters and the convection term in Eq. (1) at which it can have a quantum solution. For example, for $\eta=\gamma=q=0$, $\frac{\partial V(x)}{\partial x}=-\frac{\omega}{2}\left(\frac{x}{x_0}\right)^2$, and $x_0=\sqrt{\frac{2D}{\omega}}$, Eq. (1) for the variable $\xi=\frac{x}{x_0}$ assumes the simple form

$$\frac{2}{\omega}\frac{\partial u(\xi,t)}{\partial t}=\frac{\partial^2 u(\xi,t)}{\partial \xi^2}-\xi^2, \tag{2}$$

where ω is the parameter with dimensionality of frequency.

We seek a spatiotemporal solution of Eq. (2) in the form $u(x,t)=e^{-\nu t}\varphi_n(x)$ for $E>0$ and $t>0$. In this case, we obtain the following equation for the coordinate function $\varphi_n(x)$:

$$\varphi_n''+\left(\lambda-\xi^2\right)\varphi_n=0, \tag{3}$$

where $\lambda=\frac{2\nu}{\omega}$. The eigenfunction of Eq. (3) and the quantization condition have the well-known form [7]

$$\varphi_n(\xi)=N_0\exp\left(-\frac{\xi^2}{2}\right)H_n(\xi),\ H_n(\xi)=(-1)^n e^{\xi^2}\frac{d^n}{d\xi^n}\left[e^{-\xi^2}\right], \tag{4}$$

$$\nu_n=\omega\left(n+\frac{1}{2}\right), \tag{5}$$

where N_0 is the weighting factor (in the many-particle approach) of the distribution $u(x,t)$.

It should be noted that the quantum solution of Eq. (2) admits classical normalization $\int\limits_{-\infty}^{\infty}\int\limits_{0}^{\infty} u(x,t)\,dxdt=1$, according to which the weighting function is equal to $N_0=\frac{n!\nu}{x_0\sqrt{2\pi}(2n)!}$. Normalization by the quantum rule of the squared modulus $\int\limits_{-\infty}^{\infty}\int\limits_{0}^{\infty}|u(x,t)|^2\,dxdt=1$ is also possible. This means that quantum solution (4) (or $|u(x,t)|^2$) can be interpreted as the probability density distribution, so that the one-particle approach can be used together with the many-particle approach.

It is easy to be convinced that Eq. (2) coincides to within a constant with the Schrödinger equation for the harmonic potential with the Wick rotation of time $t\to -it$. This allows us to consider the action dimension $\tilde{h}=2Dm$, where m is the microorganism mass. Then according to the one-particle probabilistic approach, quantization condition (5) can be interpreted as a condition of quantization of the individual energy characteristic of microorganisms (dust plasma particles):

$$E_n=\tilde{h}\omega\left(n+\frac{1}{2}\right)=2Dm\omega\left(n+\frac{1}{2}\right).$$

Consideration of the action dimension $\tilde{h} = 2Dm$ allows us to introduce the quantity with dimensionality of length $\tilde{\lambda} = \frac{\tilde{h}}{mv} = \frac{2D}{v}$ being an analog of the de Broglie wavelength which at $D = 0.002\left[\frac{\text{cm}^2}{\text{s}}\right]$ and low velocities $v < 1\left[\frac{\text{cm}}{\text{s}}\right]$ satisfies the inequality $\tilde{\lambda} > 4\cdot 10^{-3}$ cm. Therefore, quantum effects can take place for slow macroscopic objects of micron sizes.

Three-dimensional analog of Eq. (2)

$$\frac{2}{\omega}\frac{\partial u(\xi,\eta,\varsigma,t)}{\partial t} = \frac{\partial^2 u(\xi,\eta,\varsigma,t)}{\partial \xi^2} + \frac{\partial^2 u(\xi,\eta,\varsigma,t)}{\partial \eta^2} + \frac{\partial^2 u(\xi,\eta,\varsigma,t)}{\partial \varsigma^2} - \left(\xi^2 + \eta^2 + \varsigma^2\right)u(\xi,\eta,\varsigma,t)$$

has a quantum solution with somewhat changed quantization condition

$$u(\xi,\eta,\varsigma,t) = e^{-\nu t}\varphi_n(\xi)\varphi_n(\eta)\varphi_n(\varsigma),$$

$$E_n = 3\tilde{h}\omega\left(n + \frac{1}{2}\right),$$

where $\xi = \frac{x}{x_0}$, $\eta = \frac{y}{x_0}$, $\varsigma = \frac{z}{x_0}$, $x_0 = \sqrt{\frac{2D}{\omega}}$, and all functions $\varphi(\xi)$, $\varphi(\eta)$, and $\varphi(\varsigma)$ have the form given by Eq. (4).

The equation

$$\frac{2}{\omega}\frac{\partial u(\tilde{\xi},\tilde{\eta},\tilde{\varsigma},t)}{\partial t} = \frac{\partial^2 u(\tilde{\xi},\tilde{\eta},\tilde{\varsigma},t)}{\partial \tilde{\xi}^2} + \frac{\partial^2 u(\tilde{\xi},\tilde{\eta},\tilde{\varsigma},t)}{\partial \tilde{\eta}^2} + \frac{\partial^2 u(\tilde{\xi},\tilde{\eta},\tilde{\varsigma},t)}{\partial \tilde{\varsigma}^2} - \left(\tilde{\xi} \pm \tilde{\eta} \pm \tilde{\varsigma}\right)^2 u(\tilde{\xi},\tilde{\eta},\tilde{\varsigma},t)$$

also has a quantum solution with

$$u(\tilde{\xi},\tilde{\eta},\tilde{\varsigma},t) = e^{-\nu t}\varphi_n(q), \quad q = \tilde{\xi} \pm \tilde{\eta} \pm \tilde{\varsigma}, \quad \tilde{\xi} = \frac{x}{\tilde{x}_0}, \quad \tilde{\eta} = \frac{y}{\tilde{x}_0}, \quad \tilde{\varsigma} = \frac{z}{\tilde{x}_0}, \quad \tilde{x}_0 = \sqrt{\frac{6D}{\omega}},$$

and $E_n = \tilde{h}\omega\left(n + \frac{1}{2}\right)$.

2. SPONTANEOUS EMISSION OF MICROORGANISMS AND DUST PLASMA PARTICLES

Microorganisms in the ionized gas representing dust plasma [8, 9] can be charged. The charged microorganisms (dust plasma particles) can generate spontaneous radiation. For additional charging of microorganisms, the diffusion mechanism can be used according to which microorganisms can be charged predominantly negatively due to different mobility values of positive and negative ions, and this charge Z expressed in units of the electron charge is [8]

$$Z = \frac{k_B T}{e_0^2} r_0 \ln\left[\left|\frac{D_+}{D_-}\right|\right],$$

where k_B is the Boltzmann constant, T is temperature, D is the diffusion coefficients of ions in the medium, Ze_0 is the microorganism charge, e_0 is the electron charge, and r_0 is the microorganism radius. For example, for air with water vapor, the positive ion diffusion coefficient is $D_+ = (0.028 - 0.029)\,\dfrac{\text{cm}^2}{\text{s}}$, and the negative ion diffusion coefficient is $D_- = (0.036 - 0.043\,)\dfrac{\text{cm}^2}{\text{s}}$. This means that microorganisms (dust plasma particles) will be charged negatively, and at $T = T_0 = 300\text{ K}$,

$$\frac{Z}{r_0} = \frac{T}{T_0}[-6 \pm 1]\mu\text{m}^{-1} = [-6 \pm 1]\mu\text{m}^{-1}.$$

Taking advantage of the theory of transient processes, it can be easily demonstrated for orthonormalized wave functions φ_n and real exponent e^{-Et} that the spectral **dimensionless** probability density P_{nk} (rather than the probability per unit time) of an individual transition of the charged microorganism (the dust plasma particle) in the dipole approximation $(k = n-1)$ is

$$\frac{dP_{nk}}{d\nu} = \frac{\nu P_0}{\nu^2 + \omega_{nk}^2},$$

where $P_0 = \dfrac{4}{3}\dfrac{q^2}{\hbar c^3}\omega_{nk}^2 |x_{nk}|^2 \Delta(t)$, $\Delta(t) = 1 + e^{-\omega_{nk}t}\left[1 - 2\cos(\nu t)\right] \approx 1$, $\hbar$ is the Planck constant, $q = Z e_0$ is the microorganism (dust plasma particle) charge, e_0 is the electron charge, $x_{nk} = \int\limits_{-\infty}^{\infty} x\varphi_k\varphi_n dx = x_0\sqrt{\dfrac{n}{2}}$, $\omega_{nk} = E_n - E_k = \omega,\ E_n > E_k$, and $x_0 = \sqrt{\dfrac{\tilde{h}}{m\omega}} = \sqrt{\dfrac{2D}{\omega}}$, so that the probability amplitude P_0, unlike standard quantum mechanics, is independent of mass. The specificity of the problem is that the frequency ω_{nk} simultaneously determines the spectral line half-width and the position of the spectral maximum, whereas $\dfrac{1}{\omega_{nk}}$ determines the lifetime of the initial state. For a comparison, we note that in standard quantum mechanics, the function $2\{1 - \cos[t\,(\nu - \omega_{nk})]\}$ arises instead of the function $\Delta(t)$, and $\dfrac{1}{|\nu - i\omega_{nk}|^2} \to \dfrac{1}{(\nu - \omega_{nk})^2}$. Therefore, the time dependence of the probability of spontaneous transition is determined by the expression $\dfrac{\sin[t(\nu - \omega_{nk})]}{(\nu - \omega_{nk})} \underset{t\to\infty}{\longrightarrow} \pi\delta(\nu - \omega_{nk})$, and the spectral probability density is $\dfrac{dP_{nk}}{d\nu} = \dfrac{4}{3}\dfrac{q^2}{\hbar c^3}\omega_{nk}^2 |x_{nk}|^2 \nu\delta(\nu - \omega_{nk})$, where $P_{nk} = \dfrac{4}{3}\dfrac{q^2}{\hbar c^3}\omega_{nk}^3 |x_{nk}|^2$ is the probability of transition per unit time, $\delta(x)$ is the delta-function which with allowance for the relaxation effect, spreads $\delta(\nu - \omega_{nk}) \to \dfrac{1}{\pi}\dfrac{\gamma}{\left[(\nu - \omega_{nk})^2 + \gamma^2\right]}$ and describes the spectral line profile of finite width γ.

It should be noted that the model of charged cell (dust plasma particle) emission in an oscillating external field remains valid for a homogeneous magnetic field. Changes in the mathematical model are minimal. The oscillator frequency in the constant homogeneous magnetic field is $\omega_h = \dfrac{Z|e|}{mc}H$, and the argument of eigenfunction (4) changes

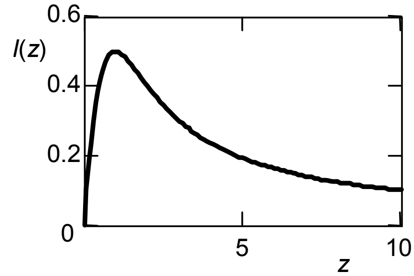

Fig. 1. Dependence of the spectral probability density of spontaneous microorganism emission $I(z)=\dfrac{dP_{nk}/dv}{P_0}$ on the dimensionless frequency $z=\dfrac{\nu}{\omega_{nk}}$.

by the constant $x \to x - a_0$, where $a_0 = -\dfrac{p_y c}{eH}$ is the x-coordinate of the circle center in the $\{xy\}$ plane if the z axis is chosen in the direction of the constant homogeneous magnetic field with components $A_x = A_z = 0$ and $A_y = Hx$. In this case, the additional possibility of control over the emission spectrum arises by changing m and H values.

Spontaneous emission of charged cells (bacteria and dust plasma particles) is also possible in a Coulomb field. Since the eigenvalues are negative in the Coulomb field, the evolution equation derived from the Schrödinger equation by the nonconventional Wick rotation of time $t \to it$ (instead of $t \to -it$ in an oscillating electric field or a homogeneous magnetic field for which $E > 0$) must be used for it.

The spectrum of spontaneous microorganism emission is shown in Fig. 1.

A maximum in the spontaneous microorganism emission spectrum is observed at the frequency $\nu = \omega_{nk} = \omega$, and the spectral line half-width is equal to $\Delta\nu = 2\sqrt{3}\omega$. For $\omega = 3\cdot 10^{12}\,\text{Hz}$, $Z = 100$, and $D = 0.002\left[\dfrac{\text{cm}^2}{\text{s}}\right]$, the probability amplitude is $P_0 \approx \alpha Z^2\left(\dfrac{x_0}{\lambda}\right)^2 \approx 10^{-8}\alpha$ (here $\alpha \approx \dfrac{1}{137}$ is the fine structure constant). In this case, the maximum of the spectral probability density is observed at the wavelength $\lambda_{\max} = \dfrac{c}{\omega} = 10^{-2}\,\text{cm}$ ($E_{\max} = \tilde{h}\omega = 2Dm\omega \approx 10^{-7}\,\text{J}$ and $m = 10^{-10}\,\text{g}$), so that the maximum energy of spontaneous emission is $P_0 E_{\max} \approx 10^{-18}\,\text{J} \approx 10\,\text{eV}$.

It should be noted that the maximum energy of spontaneous emission of cells (bacteria or dust plasma particles) for $\omega = 1.8\cdot 10^{10}\,\text{Hz}$, $Z = 100$, $D = 0.002\left[\dfrac{\text{cm}^2}{\text{s}}\right]$, and $m = 10^{-10}\,\text{g}$ is $P_0 E_{\max} \approx 3.74\cdot 10^{-23}\,\text{J}$, which corresponds to the temperature $T = \dfrac{P_0 E_{\max}}{k_\text{B}} \approx 2.7\,\text{K}$ ($\lambda_{\max} \approx 1.7\,\text{cm}$) coinciding with the temperature of relic radiation. The corresponding oscillator at the frequency $\omega_h = \dfrac{Z|e|}{mc}H = 1.8\cdot 10^{10}\,\text{Hz}$ is capable of generating the homogeneous magnetic field $H = 10^2\,\text{G}$. Since microorganisms can not only generate photons with relic radiation frequency, but also absorb relic photons, this means that in the modern era, life on the Earth can need relic radiation.

It is important to note that for $H > 10^4\,\text{G}$, the dust plasma of the Universe is capable of generating quanta with high energy $E_{\max} = \tilde{h}\omega = 2Dm\omega > 10^{-7}\,\text{J} \approx 10^3\,\text{GeV}$ ($\lambda_{\max} < 10^{-2}\,\text{cm}$) by the mechanism of spontaneous emission, which is caused by the action dimension $\tilde{h} = 2Dm$ (low energy on the macroscopic level ($10^{-7}\,\text{J}$) is obviously high ($10^3\,\text{GeV}$) on the quantum level). This means that the possibility arises of creating a generator of hard photons with energy higher than 10^3 GeV. The charged dust (live) plasma particles in this generator have to take part in radial diffusion-type motion in the plane perpendicular to the magnetic field direction. The corresponding generator can be created, for example, based on the centrifuge whose magnetic field is directed along the rotation axis. It must be borne in mind that problems can arise with detection of hard photons, since they can generate showers of both well-known particles and particles unknown to science in the process of interaction with the environment. The system of microorganisms in plasma of various types is capable of self-organizing and forming ordered structures, crystallization, and phase transitions, which can be used in different fields of science and technology.

CONCLUSIONS

The investigation performed allows us to conclude that the Fisher–Kolmogorov–Petrovskii–Piskunov equation with oscillating convection and linear diffusion describing the dynamics of biological systems can have one-particle solution describing the quantum dynamics of **macroscopic** systems of micron sizes. This means that this equation can be the basic one for quantum biology, biological electronics, synthetic biology engaged in the transformation of bacteria into mini-factories, and quantum microphysics (quantum mechanics of micron-sized particles) that can be an alternative to nanophysics. After redefinition of the dynamic variable $u(x,t)$, the FKPP equation can be used in financial mathematics. Spontaneous emission of cells (bacteria or dust plasma particles) can be related to relic radiation that can comprise the component caused by spontaneous emission of dust plasma in the Universe. The truncated FKPP equation can be used in quantum geometrodynamics to solve the problem of time asymmetry of the Universe [11–35].

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