E4-2011-54

V. K. Ignatovich *

ON EPR PARADOX, NO ENTANGLEMENT THEOREM FOR SEPARATE PARTICLES AND CONSEQUENCES

* E-mail: ignatovi@nf.jinr.ru

Игнатович В.К. Е4-2011-54
ЭПР-парадокс, теорема об отсутствии перепутанных состояний удаленных частиц и ее следствия

Рассмотрен ЭПР-парадокс [1]. Показано, что необходимое переопределение физических величин приводит к разрешению парадокса. Показано также, что из самой логики ЭПР следует отсутствие переплетенных состояний удаленных частиц и нелокальности в квантовой механике. Рассмотрена модель экспериментов по регистрации на совпадение пары фотонов, рождаемых в нелинейных кристаллах, и аналитически продемонстрировано, как неравенства Белла могут нарушаться в полностью локальной квантовой механике.

Работа выполнена в Лаборатории нейтронной физики им. И. М. Франка ОИЯИ.

Сообщение Объединенного института ядерных исследований. Дубна, 2011

Ignatovich V.K. E4-2011-54
On EPR Paradox, No Entanglement Theorem for Separate Particles and Consequences

EPR paper [1] is reconsidered. Unavoidable redefinition of values of physical quantities is shown to resolve the paradox. Entangled states according to EPR logic are shown not to exist, and therefore nonlocality in quantum mechanics is absent. Violation of Bell's inequalities in coincidence experiments with parametrically downconversion photons is shown not to mean a rejection of quantum mechanical locality. Experiments to check the natural correlation of photon polarizations without entangled states are proposed. Consequences of absence of the entangled states are discussed.

The investigation has been performed at the Frank Laboratory of Neutron Physics, JINR.

Communication of the Joint Institute for Nuclear Research. Dubna, 2011

1. INTRODUCTION

In EPR paper [1] it is shown that on the one hand, from the common sense logic it follows that a particle can have position and momentum simultaneously, but on the other hand, the particle cannot have them because of uncertainty relations. This contradiction is called the EPR paradox. We will show that the contradiction arises from an incorrect definition of the values of physical quantities as eigen values of the corresponding operators. Such a definition leads to an inconsistency. The only way to correct this inconsistency is to redefine the notion of a physical quantity. After redefinition the paradox disappears.

Another point of EPR paper is introduction of entangled states of two particles, which is a sum of different products of independent wave functions. Entanglement leads to a nonlocality, i.e., to action at a distance, when a measurement on one particle immediately affects the state of another one. We show that the logic of the EPR paper itself proves that the entangled states do not exist.

However the last 30 years an avalanche of publications appeared in literature, where entanglement as a typical sign of nonlocality is «proven» even experimentally. The start to all this activity gave John Bell [2]. He considered a possibility to replace nonlocal quantum theory by a local and «realistic», i.e., classical physical theory, and derived the well-known inequality. He proved himself that the nonlocal quantum mechanics violates the inequality, therefore the nonlocal quantum mechanics cannot be replaced by local and «realistic», i.e., classical physical theories.

Since then the number of inequalities multiplied [3–5], but the goal of all the experiments dealing with them remained identical: to prove that they are violated, therefore no local realistic theory can replace nonlocal quantum mechanics.

It seems that a possibility to replace quantum mechanics with a classical theory must be considered absolutely differently (see, for instance, [6, 7]), therefore we do not want to follow here the realistic approach by J. Bell. Our goal is to check, whether experiments on violation of Bell's inequalities really prove that we cannot abandon entangled states and nonlocality in quantum mechanics.

It is necessary to tell here that Bell's inequalities should not be violated in local quantum mechanics, so violation of these inequalities in an experiment looks like a proof of nonlocality. However the close inspection of some experimental data (for instance, in atomic cascade decay [8–11]) shows that the proof is unreliable because of doubtful subtraction of the background (see, for instance, [7, 12] and also the recently reported long-distance experiment [13]).

The most recent experiments were performed with parametrically down conversion photons (PDCP) [14–16]. So the question is how reliable are these experiments. We are not yet ready to analyze all of them here. We want only to show analytically, that in the local quantum mechanics Bell's inequalities can be also violated. So their violation does not prove existence of entangled states of separated particles.

This paper stemmed from a desire to understand the publication [17], which after [18] presented results of numerical experiment with not entangled photons, where Bell's inequalities were found to be violated because of time lag of two photons on their way to registration stations. This numerical experiment is interpreted here analytically.

2. INCONSISTENCY IN THE EPR PAPER

In [1] it is said: If ψ is an eigenfunction of the corresponding operator A, that is, if

$$\psi' \equiv A\psi = a\psi, \tag{[1]1}$$

where a is the number, then the physical quantity A has with certainty the value a whenever the particle is in the state given by ψ.

In particular, the momentum p is defined for the wave function represented by a plane wave

$$\psi = \exp\left(2\pi i p_0 x/h\right), \tag{[1]2}$$

since the eigenvalue of the momentum operator $\hat{\boldsymbol{p}} = (h/2\pi i)d/dx$ for this wave function is p_0. Thus, in the state given by Eq. ([1]2), the momentum has certainly the value p_0. It thus has meaning to say that the momentum of the particle in the state given by Eq. ([1]2) is real.

In such a state, however, we have no information about the particle position. According to EPR [1], we can only say that the relative probability that a measurement of the coordinate will give a result lying between a and b is

$$P(a,b) = \int\limits_a^b |\psi(x)|^2 dx = b - a. \tag{[1]6}$$

We must point out this equation as inconsistent one, because it cannot be accepted as a probability. It is not dimensionless, and it is not normalizable.

All the textbooks on quantum mechanics ignore this inconsistency. They use the modified plain waves $\exp(ikx)/\sqrt{L}$ instead of ([1]2) with some large linear scale L. Then instead of ([1]6) we get $(b-a)/L$, which is dimensionless. For $|b-a|$ to be not larger than L, the particle is claimed to be in an impenetrable box. However, in this case the wave function must look like $\sin(\pi nx/L)$ with integer n, and such a function is not an eigenfunction of the momentum operator. Therefore the momentum does not exist in such a box.

3. CORRECTION OF THE INCONSISTENCY

To have physical value of momentum and to avoid inconsistency in determination of its position, we must introduce a wave packet for the wave function of a particle, and redefine the momentum and position of the particle as expectation values of operators:

$$p=\int\psi^{+}(x')\hat{p}\psi(x')dx',\quad x=\int\psi^{+}(x')\hat{x}\psi(x')dx',\tag{1}$$

then they exist simultaneously and the EPR paradox disappears.

Noncommutativity of operators $\hat{x}$ and $\hat{p}$ does not preclude simultaneous precise definitions of x and p according to Eq. (1), therefore uncertainty relations have nothing to do with quantum mechanics. They are valid in quantum mechanics because they are valid in every branch of physics dealing with functions. Uncertainty relation is only a mathematical theorem, which relates range of any function to the range of its Fourier image [6].

The textbooks in quantum mechanics do not accept relations of Eq. (1) as values of physical quantities because with such definitions we have dispersions:

$$\Delta x^2=\int\psi^{+}(x')(\hat{x}-x)^2\psi(x')dx',\quad \Delta p^2=\int\psi^{+}(x')(\hat{p}-p)^2\psi(x')dx'.\tag{2}$$

However, the dispersion is not a statistical indefiniteness, but a characteristic of the wave packet. For illustration, let us look at any object of nonzero size. Can we say what is its position? Yes, we can, but the position point is a matter of definition. It can be the center of gravity, or geometrical center, or the closest point to an observer. For every extended in space object, we can also find a dispersion of the previously defined position, and this dispersion characterizes the form and the size of the object.

4. ENTANGLED STATES OF SEPARATED PARTICLES DO NOT EXIST

The EPR paper considers two particles, which interacted at some past moment and then flew far apart. Notwithstanding of how large is the distance between them they have a common «entangled» wave function

$$\Psi(x_1,x_2)=\sum_n\phi_n(x_1)u_n(x_2).\tag{3}$$

According to EPR logic, if particle 1, after measurement is found in the state $\phi_m(x_1)$, then the state of particle 2 is $u_m(x_2)$. But particle 2 is far away from particle 1 and is not perturbed by measurements of 1, therefore particle 2 had the state $u_m(x_2)$ before the measurement.

Following this logic, we immediately conclude that if particle 2 had the state $u_m(x_2)$ before the measurement of 1, then, according to Eq. (3), particle 1 before the measurement had the wave function $\phi_m(x_1)$, i.e., the wave function of two particles before the measurement was not Eq. (3), but a simple product

$$\Psi(x_1, x_2) = \phi_m(x_1)u_m(x_2), \tag{4}$$

and the measurement only revealed what product it really was. So the entangled state of Eq. (3) represents only a list of possible states for separated particles. The total sum of Eq. (3) is forbidden in quantum mechanics like forbidden are the exponentially growing solutions of the Schrödinger equation.

However we can proceed even further. Since wave function of a particle is a normalizable wave packet, the wave function of two particles is not a product, but a sum of wave packets of separated particles, because the product annuls with the time. It is an additional argument against entanglement of separated particles.

5. BOHM–AHARONOV VERSION OF THE EPR ENTANGLED STATE

Bohm–Aharonov [19] considered EPR paradox and entanglement in terms of spin operators of spin 1/2 particles, and the photon polarizations. We will omit discussion of spin 1/2 particles and limit ourselves only to the photon polarizations.

Let us imagine the experiment shown in Fig. 1.

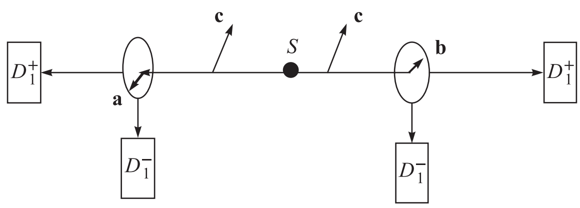

Fig. 1. Scheme of the experiment on coincident measurement of a correlation of polarization of two photons radiated by the source S. The source radiates two photons with parallel polarizations $\mathbf{c}$ which has a uniform angular distribution around direction of the photons flight path. Polarizing beam splitters with axes $\mathbf{a}$ and $\mathbf{b}$ transmit photons along one of the two channels toward the detectors $D_{1,2}^{\pm}$

The source S radiates photons, which can be assumed to be in an entangled state

$$|\psi_0(1,2)\rangle = \frac{1}{\sqrt{2}}\Big[|V_1\rangle|V_2\rangle + |H_1\rangle|H_2\rangle\Big], \tag{5}$$

where $|V_i\rangle$, $|H_i\rangle$ denote states of ith photon with polarization along orthogonal vertical and horizontal axes. Though the wave packets of photons fly apart, their polarization is claimed [16] to be in the state of Eq. (5). Therefore no photon has an individual polarization before measurement. The entanglement like Eq. (5) is «proven» by the experimental data, which demonstrate violation of Bell's inequalities. The inequalities would not be violated if the photons could fly apart with their individual polarizations.

Nevertheless, we suppose that the radiated photons can have their own linear polarizations directed along some unit vector $\mathbf{c}$, which has random distribution around the direction of propagation, and will show that notwithstanding of their individuality the correlation of photon polarization can violate Bell's inequality. It contradicts the wide spread belief and supports the results of the numerical experiment reported in [14].

5.1. Bell's Inequality. There are many inequalities called «Bell's inequalities». Only two of them belong to Bell himself [5]. One was derived in 1964 [2], and the other one in 1971 [3]. The last inequality, which was also derived earlier (see [4]), looks like

$$-2 \leqslant S \leqslant 2, \tag{6}$$

where

$$S = E(\mathbf{a}, \mathbf{b}) - E(\mathbf{a}, \mathbf{b}') + E(\mathbf{a}', \mathbf{b}') + E(\mathbf{a}', \mathbf{b}), \tag{7}$$

and $E(\mathbf{a}, \mathbf{b})$ is a correlation of polarizations of two particles registered after two analyzers with their axes along unit vectors $\mathbf{a}$ and $\mathbf{b}$ in an experiment depicted in Fig. 1. This correlation was presented by Bell as

$$E(\mathbf{a}, \mathbf{b}) = \int d\lambda \rho(\lambda) A(\mathbf{a}, \lambda) B(\mathbf{b}, \lambda), \tag{8}$$

where λ is some hidden parameter with statistical distribution $\rho(\lambda)$, and two functions $A(\mathbf{a}, \lambda)$ and $B(\mathbf{b}, \lambda)$ are some classical functions, which for a given parameter λ have one of three predetermined values ± 1 or 0. The first two values correspond to registration by detectors $D_i^{\pm}$ and the last value corresponds to loss of the particle. Let us take into account that, though it is said that particles are measured in coincidence, there is no time or time window in Eq. (8). It means that the width w of the time window is large enough or $w = \infty$, and no other particle can enter any of the detectors inside this window.

5.2. Definition of the Correlation. We will not use classical description with predetermined functions. Instead, we suppose that the radiated particles are not entangled, have their individual polarizations, and interact with analyzers $\mathbf{a}$ and $\mathbf{b}$ quantum mechanically, i.e., probability of a photon with polarization $\mathbf{c}$ to be transmitted through the analyzer with its axis $\mathbf{a}$ is equal to $P_+(\mathbf{a}) = (\mathbf{a} \cdot \mathbf{c})^2 = \cos^2(\alpha - \xi)$ along one channel, and $P_-(\mathbf{a}) = 1 - (\mathbf{a} \cdot \mathbf{c})^2 = \sin^2(\alpha - \xi)$ along another channel, where α, ξ are azimuthal angles of vectors $\mathbf{a}$ and $\mathbf{c}$ defined with respect of some axis normal to the propagation direction. In the following, we will choose this axis along the vector $\mathbf{a}$, so $\alpha = 0$. We also suppose that the angle ξ has the uniform distribution $d\xi/(2\pi)$. Thus, our correlation looks as in [14]:

$$E(\mathbf{a},\mathbf{b}) \equiv E(\beta) = \frac{P_{++}(\mathbf{a},\mathbf{b}) + P_{--}(\mathbf{a},\mathbf{b}) - P_{+-}(\mathbf{a},\mathbf{b}) - P_{-+}(\mathbf{a},\mathbf{b})}{P_{++}(\mathbf{a},\mathbf{b}) + P_{--}(\mathbf{a},\mathbf{b}) + P_{+-}(\mathbf{a},\mathbf{b}) + P_{-+}(\mathbf{a},\mathbf{b})}, \quad (9)$$

where, say, $P_{\pm}(\mathbf{a},\mathbf{b})$ is the probability of registration by detectors $D^{\pm}_{1,2}$ in coincidence, and β is the angle between vectors $\mathbf{a}$ and $\mathbf{b}$.

We suppose the analyzers to be without losses and efficiency of registration by the detectors after analyzers are all the same and can be put to unity. Then the probabilities in Eq. (9) can be calculated analytically. For instance,

$$P_{++}(\mathbf{a},\mathbf{b}) \equiv P_{++}(\beta) = \int \frac{d\xi}{2\pi} \cos^2(\xi)\cos^2(\beta-\xi)\Theta(|t_1-t_2|<w), \quad (10)$$

where w is the width of the coincidence window, $t_{1,2}$ are the time delays of the moment of registration and Θ is the step function equal to unity, when inequality in its argument is satisfied, and — to zero in the opposite case.

Our goal is to calculate all these probabilities and to show for some particular case that the inequality

$$S = 3E(\beta) - E(3\beta) < 2, \quad (11)$$

where $\beta = \beta_0 = \pi/8$, can be violated notwithstanding that our particles are not entangled.

5.3. Calculation of the Probabilities. In the following, we, like in [17], suppose that the time difference $\Delta t = |t_1 - t_2|$ depends on angles ξ, β and on registration channels.

5.3.1. Calculation of the Probabilities for Diagonal Channels. Let us consider the sum of probabilities of Eq. (10) for diagonal channels. It can be represented as

$$\begin{aligned} Q_d(\beta) &\equiv P_{++}(\beta) + P_{--}(\beta) = \\ &= \frac{1}{4}\int \frac{d\xi}{2\pi}\Big(2+\cos(2\beta)+\cos(2(2\xi-\beta))\Big)\Theta(|t_1-t_2|<w). \end{aligned} \quad (12)$$

We suppose that the time delay Δt changes with the change of the angle β. So, for a given β and small enough w, the Θ-function restricts integration over ξ to some interval $\Delta(\xi) \leqslant 2\pi$. Therefore, Eq. (12) is reduced to

$$Q_d(\beta) = \frac{1}{(8\pi)}\left(\Delta(\beta)[2+\cos(2\beta)] + \int\limits_{\xi_1(\beta)}^{\xi_2(\beta)} d\xi \cos(4\xi - 2\beta)\right), \quad (13)$$

where $\Delta(\beta) = \xi_2(\beta) - \xi_1(\beta)$. Equation (13) after integration can be represented as

$$Q_d(\beta) = \frac{\Delta(\beta)}{(8\pi)} \left(2 + \cos(2\beta) + \frac{\sin(2\Delta(\beta))}{2\Delta(\beta)} \cos(2(\xi_2(\beta) + \xi_1(\beta)) - 2\beta) \right). \quad (14)$$

Now we have to define the limits of integration. For simplicity, we restrict our considerations only to the particular cases $\beta = \beta_0 = \pi/8$ and $\beta = 3\beta_0$. For the first case, we take the interval $(\mathbf{c}_1, \mathbf{c}_2)$ for photon polarizations $\mathbf{c}$, in which both particles are registered, to overlap β_0, as is shown in Fig. 2, a, and in the second case, the interval is inside $3\beta_0$. Moreover we suppose that $\gamma = \beta_0$ to stop registration of particles in coincidence, when angular distance of ξ from axis of one of two analyzers is larger than $2\beta_0$.

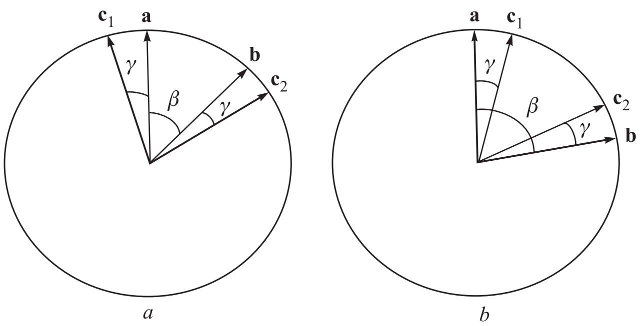

Fig. 2. Restriction of integration interval $(\mathbf{c}_1, \mathbf{c}_2)$. a) In the case $\beta = \beta_0$ the integration interval overlaps angle β. b) In the case of $\beta = 3\beta_0$ the integration interval is inside β. In calculations we take $\gamma = \beta_0$ and such a choice means that time interval Δt of detector registrations is inside coincidence window w, when angle between photon polarization and every analyzer axis is not larger than $2\beta_0$

With such a choice of the angular limits, Eq. (14) becomes

$$Q_d(\beta_0) = \frac{3\beta_0}{(8\pi)} \left(2 + \cos(2\beta_0) + \frac{\sin(6\beta_0)}{6\beta_0} \right), \quad (15)$$

and

$$Q_d(3\beta_0) = \frac{\beta_0}{(8\pi)} \left(2 + \cos(6\beta_0) + \frac{\sin(2\beta_0)}{2\beta_0} \right). \quad (16)$$

5.3.2. Calculation of the Probabilities for Nondiagonal Channels. Now we calculate nondiagonal channels. In this calculation we take into account that the cross channels are equivalent to the diagonal channels, where one of the analyzer axes is turned by additional angle $\pi/2$. It means that for $\beta = \beta_0$, the nondiagonal probabilities are equal to diagonal ones but with $\beta = \pi/2 - \beta_0 = 3\beta_0$. This consideration facilitates our calculations very much.

The sum of nondiagonal probabilities

$$Q_{\rm nd}(\beta_0) \equiv P_{+-}(\beta_0) + P_{-+}(\beta_0) =$$
$$= \int \frac{d\xi}{2\pi}[\sin^2(\xi)\cos^2(\beta_0-\xi)+\cos^2(\xi)\sin^2(\beta_0-\xi)]\Theta(|t_1-t_2|<w) \quad (17)$$

can be transformed to

$$Q_{\rm nd}(\beta_0) = \int \frac{d\xi}{8\pi}[2-\cos(2\beta_0)+\cos(4\xi-2(\pi/2-\beta_0))]\Theta(|t_1-t_2|<w), \quad (18)$$

and, since $\pi/2-\beta_0 = 3\beta_0$, this integral is calculated in the limits shown in Fig. 2, *b*. Integration over this interval leads to

$$Q_{\rm nd}(\beta_0) = \frac{\beta_0}{8\pi}\left[2-\cos(2\beta_0)+\frac{\sin(2\beta_0)}{2\beta_0}\right]. \quad (19)$$

The similar considerations for nondiagonal terms in the case of $\beta = 3\beta_0$ immediately gives

$$Q_{\rm nd}(3\beta_0) = \frac{3\beta_0}{8\pi}\left[2-\cos(6\beta_0)+\frac{\sin(6\beta_0)}{6\beta_0}\right]. \quad (20)$$

5.3.3. Calculation of Correlations and S for $\beta = \beta_0 = \pi/8$. Substitution of (15), (16), (19), (20) into Eq. (9) for $\beta_0 = \pi/8$ gives

$$E(\beta_0) = \frac{4+4\cos(2\beta_0)+\dfrac{\sin(6\beta_0)}{2\beta_0}-\dfrac{\sin(2\beta_0)}{2\beta_0}}{8+2\cos(2\beta_0)+\dfrac{\sin(6\beta_0)}{2\beta_0}+\dfrac{\sin(2\beta_0)}{2\beta_0}} = \frac{4+2\sqrt{2}}{8+\sqrt{2}+4\sqrt{2}/\pi}, \quad (21)$$

$$E(3\beta_0) = \frac{-4+4\cos(6\beta_0)+\dfrac{\sin(2\beta_0)}{2\beta_0}-\dfrac{\sin(6\beta_0)}{2\beta_0}}{8-2\cos(6\beta_0)+\dfrac{\sin(2\beta_0)}{2\beta_0}+\dfrac{\sin(6\beta_0)}{2\beta_0}} = \frac{-4-2\sqrt{2}}{8+\sqrt{2}+4\sqrt{2}/\pi}. \quad (22)$$

Substitution of these values into Eq. (11) for S shows that

$$3E(\beta_0) - E(3\beta_0) = 2\frac{1+\sqrt{2}}{\sqrt{2}+1/4+1/\pi} = 2.44, \quad (23)$$

i.e., Bell's inequality (Eq. (11)) is violated though we considered photons with individual polarizations.

6. CONCLUSION

We have shown that EPR paradox does not exist, that uncertainty relations have nothing to do with quantum mechanics, that entangled states do not exist, and experiments with cascade decay of excited calcium atom do not prove nonlocality of quantum mechanics. We did not analyze here experiments with parametric down conversion of photons because of volume restriction. Some of them were already analyzed in [12], and it was shown that they also do not prove nonlocality of quantum mechanics. It proves that violation of Bell's inequalities in an experiment is the necessary, but not the sufficient condition for nonlocality of quantum mechanics.

Acknowledgement. The author would like to thank Dr. Filipp Ignatovich of Lumetrics Inc., Prof. Guenakh Mitselmakher of Florida University, Prof. Lukas Novotny, Prof. Nick Bigelow, and Dr. Svetlana Lukishova of Rochester University for their interest and assistance.

REFERENCES

1. *Einstein A., Podolsky B., Rosen N.* // Phys. Rev. 1935. V. 47. P. 777.
2. *John S. Bell.* On the EPR Paradox // Physics. 1964. V. 1. P. 195–200.
3. *John S. Bell.* Foundations of Quantum Mechanics / Ed. B. d'Espagnat. N. Y.: Academic Press, 1971. P. 171–81.
4. *Clauser J. F. et al.* Proposed Experiment to Test Local Hidden-Variable Theories // Phys. Rev. Lett. 1969. V. 23. P. 880.
5. *Clauser J. F., Shimony A.* Bell's Theorem: Experimental Tests and Implications // Rep. Prog. Phys. 1978. V. 41. P. 1881–1927.
6. *Ignatovich V. K.* On Uncertainty Relations and Interference in Quantum and Classical Mechanics // Concepts of Physics. 2006. V. III. P. 11–22.
7. *Utsuro M., Ignatovich V. K.* Handbook of Neutron Optics. Weinheim: Wiley-VCH, 2010. Ch. 10.
8. *Aspect A., Grangier P., Roger G.* Experimental Tests of Realistic Local Theories via Bell's Theorem // Phys. Rev. Lett. 1981. V. 47. 1981. P. 460.
9. *Kocher C. A., Commins E. D.* Polarization Correlation of Photons Emitted in an Atomic Cascade // Phys. Rev. Lett. 1967. V. 18. P. 575.
10. *Aspect A., Grangier P., Roger G.* Experimental Realisation of Einstein–Podolskii–Rosen–Bohm Gedankenexperiment: A New Violation of Bell's Inequalities // Phys. Rev. Lett. 1982. V. 49. P. 91.
11. *Aspect A., Dalibard J., Roger G.* Experimental Test of Bell's Inequalities, Using Time-Varying Analyzers // Phys. Rev. Lett. 1982. V. 49. P. 1804.
12. *Ignatovich V. K.* On EPR Paradox, Bell's Inequalities and Experiments That Prove Nothing // Concepts of Physics, the Old and New. 2008. V. 5. P. 227.

13. *Ursin R. et al.* Free-Space Distribution of Entanglement and Single Photons over 144 km. quant-ph/0607182.
14. *De Raedt H. et al.* Event-Based Computer Simulation Model of Aspect-Type Experiments Strictly Satisfying Einstein's Locality Conditions // J. Phys. Soc. (Japan). 2007. V. 76. P. 104005; arXiv:0712.2565v1 [quant-ph].
15. *Larsson J. A., Gill R. D.* Bell's Inequality and the Coincidence-Time Loophole // Europhys. Lett. V. 67, No. 5. 2004. P. 707–713.
16. *Genovese M.* Research on Hidden Variable Theories: A Review of Recent Progresses // Phys. Rep. 2005. V. 413. P. 319–396.
17. *Ignatovich F. V., Ignatovich V.* Reflection of Light from an Anisotropic Medium. arXiv:1010.0352(physics.gen-ph); Plain Electromagnetic Waves in Anisotropic Media. arXiv:1101.0829.
18. *Bohm D., Aharonov Y.* Discussion of Experimental Proof for the Paradox Einstein, Rosen, and Podolsky // Phys. Rev. 1957. V. 108. P. 1070.
19. *Hayashi M. et al.* Hypothesis Testing for an Entangled State Produced by Spontaneous Parametric Down Conversion // Phys. Rev. A. 2006. V. 74. P. 062321.
20. *Paul G. et al.* Ultrabright Source of Polarization-Entangled Photons // Phys. Rev. A. 1999. V. 60. P. R773.
21. *David Mermin N.* From Cbits to Qbits: Teaching Computer Scientists Quantum Mechanics // Am. J. Phys. 2003. V. 71, No. 1. P. 23.

Received on June 6, 2011.

Корректор *Т. Е. Попеко*

Подписано в печать 31.08.2011.
Формат $60 \times 90/16$. Бумага офсетная. Печать офсетная.
Усл. печ. л. 0,93. Уч.-изд. л. 1,26. Тираж 310 экз. Заказ № 57410.

Издательский отдел Объединенного института ядерных исследований
141980, г. Дубна, Московская обл., ул. Жолио-Кюри, 6.
E-mail: publish@jinr.ru
www.jinr.ru/publish/