 © 2020 Kvantovaya Elektronika and IOP Publishing Limited

https://doi.org/10.1070/QEL17191

Is a nondemolition measurement of the quantum state vector collapse of a remote localised system possible?

A.V. Belinsky

Abstract. **By the example of an experiment that implements, according to its authors, Wigner friends' paradox, the impossibility of measuring the state vector collapse of a remote localised system is shown. It is also found that the objectivity of the results of quantum measurements is not violated in this case.**

Keywords: *Wigner friends' paradox, quantum nondemolition measurements, Bell inequality, Clauser–Horne–Shimony–Holt inequality, quantum state vector, von Neumann projection postulate, 'no communication theorem'.*

1. Introduction

Recently, there has been sparked a noticeable growth of interest in elucidating the ontological status of the wave function and the quantum state vector, which belong to the basic concepts of quantum mechanics. Manifestations of so-called quantum nonlocality and many quantum paradoxes do not find indisputable and generally accepted consistent interpretations. In this regard, more and more adherents of informational interpretation appear, the origins of which were outlined by Niels Bohr [1] and further developed, for example, in work [2, 3].

As one of the arguments in favour of this interpretation, the so-called Wigner friends' paradox is put forward, which, according to Proietti et al. [4], has received experimental confirmation.

From the very beginning, after physicists became convinced that entangled states and related nonlocality phenomenon exist in nature, attempts were made to use them to transmit information (see, for example, paper [5] and references therein). These attempts were based on the existence of quantitative characteristics of the entanglement value (Schmidt parameter, Bell inequalities of the Clauser–Horne–Shimony–Holt type (CHSH) [6], the Perez–Gorodetsky criterion, etc.). It was assumed that by measuring the values of these parameters, it would be possible to obtain information about the processes occurring with different parts of the entangled state, and use them to transfer information over macroscopic distances. The development of this direction went along the way of increasing the number of entangled particles and detectors and complicating the processes of interaction between them.

A.V. Belinsky Faculty of Physics, Lomonosov Moscow State University, Vorob'evy Gory, 119991 Moscow, Russia;
e-mail: belinsky@inbox.ru, belinsky@physics.msu.ru

Received 17 November 2019; revision received 17 January 2020
Kvantovaya Elektronika **50** (5) 469–474 (2020)
Translated by M.A. Monastyrskiy

Over the past more than 30 years, a number of principal schemes aimed at implementing such ideas have been theoretically analysed and experimentally verified, starting with Aspect's classic works [7–10] on verification of the Bell inequality [11].

Proietti et al. [4] describe an experiment that raises a number of questions related not only to the possibility of quantum information exchange, but also to the objectivity of the results of quantum measurements in general. Is it possible to transmit a signal by making a collapsing measurement of one of a pair of entangled particles without a classical communication channel? Can remote observers get different measurement results for the same quantum object? This paper attempts to answer these questions.

2. Experiment reproducing Wigner friends' paradox [4]

A pair of photons entangled by polarisation is sent to Alice and Bob's friends, each to his own, to a separate laboratory. Alice and Bob themselves, who are also located at different places, can either get the same result in a nondemolition way, i.e. the values A_0 and B_0 of dichotomous variables which are equal to +1 or –1 depending on the polarisation state of the recorded photons, or, according to the authors, measure whether a collapse of the superposition state of entangled photons has occurred. To do this, both Alice and Bob using the same detectors with a small upgrade of the experimental setup, which consists in the introduction of additional beam splitters into the scheme, also obtain dichotomous values of A_1 and B_1, equal to +1 or –1.

Thus, in each act of measurement, there are well-defined values A_0 and B_0, i.e., the collapse objectively took place. However, Alice and Bob, while recording A_1 and B_1, observe quantum interference, which supposedly indicates the opposite. How do authors propose to verify this [4]? From the values A_i and B_i they compose the Bell inequality of the CHSH type [6],

$$S = |\langle A_1B_1\rangle + \langle A_1B_0\rangle + \langle A_0B_1\rangle - \langle A_0B_0\rangle| \le 2, \qquad (1)$$

and it is violated in the experiment, which indicates the absence of certain values of A_0, A_1, B_0, B_1 simultaneously, although they are all measured and known, including A_0 and B_0.

Thus, during the same experiment, there are certain measured values of A_0 and B_0, but statistical observations of the mean values included in (1) indicate that certain values of A_0 and B_0 cannot exist simultaneously with A_1 and B_1. But they are measured and exist! Based on this apparent contradiction, Proietti et al. [4] conclude that there is no objective reality.

After all, the same experiment cannot give mutually exclusive results. Is everything correct here?

3. Features of the CHSH inequality

To find out the consequences of violating the CHSH inequality, we should turn to its simplest derivation [12, 13]. Let all four values A_i, B_i simultaneously have definite values a_0, a_1, b_0, and b_1 equal to +1 or –1. Then one can derive from them the expressions:

$$a_1b_1 + a_1b_0 + a_0b_1 - a_0b_0 = a_1(b_1 + b_0) + a_0(b_1 - b_0)$$
$$= b_1(a_1 + a_0) + b_0(a_1 - a_0) = \pm 2, \qquad (2)$$

from which inequality (1) follows.

It is important to note that the concept of *definiteness of values* a_0, a_1, b_0, b_1 in the derivation of the Bell inequalities, including those of the CHSH type, makes sense not in their determinism, because they are random, but of the fact that they exist *simultaneously* in each act of measurement. Bell inequalities are violated when not all four values are measured simultaneously, but only two of them, or three of six or four of eight, as in the Greenberger–Horne–Zeilinger (GHZ) paradox [14]. This is due to the fact that the root cause of violation of classical Bell inequalities is the description of the observables entering these inequalities by noncommuting operators in the framework of the quantum-mechanical approach [12]. Therefore, simultaneous direct measurements of them are not performed, while inequalities are constructed from pairs (CHSH), triples or quadruples (GHZ) of the values included in them.

At the first stage of the experiment [4], all the observers (Alice, Bob, and their friends) measure the same values A_0 and B_0, and, of course, obtain the same results. Of these, the average value $\langle A_0B_0\rangle$ is compiled. Then, Alice and Bob install additional beam splitters in their meters and proceed to measure A_1 and B_1. In this case, all four values A_0, B_0, A_1 and B_1 are measured simultaneously (Alice and Bob measure A_1 and B_1, and A_0 and B_0 are measured by their friends) and simultaneously have certain values a_0, a_1, b_0, and b_1. If we compose the averages from them, which appear in inequality (1), then it will certainly not be violated by virtue of (2), since the simultaneous existence of certain values a_0, a_1, b_0, and b_1 is a sufficient condition for fulfilling (1). Even if the beam splitter is only installed for Alice or Bob, three of the four values A_0, B_0, A_1 and B_1 will be measured simultaneously, and again, by virtue of (2), inequality (1) cannot be violated, since one of the brackets in (2) will vanish. Why ever this inequality turned out violated in work [4]?

If we discard the possibility of some kind of experimental error in work [4], the only explanation for the resulting inconsistency is that the average $\langle A_0B_0\rangle$ at the first stage of the experiment is not identical to the average $\langle A_0B_0\rangle$ at its subsequent stages. Why can this happen? The fact is that in work [4], the recording of all six photons is only considered informative. Other implementations are simply discarded. Thus, when Alice's and/or Bob's measurement conditions are changed (by installing beam splitters), a selection of the measuring counts of their friends occurs, and the average $\langle A_0B_0\rangle$ may change.

Does this mean that there is no objective measurement? No. After all, a change in the meter can naturally cause a change in the measurement results. Objectivity could only suffer in the case of a truly nondemolition measurement, when the Alice's and/or Bob's results would have in no way affected the results of their friends. However, as will be shown in the following sections, this is hardly possible. But at the beginning, we should give additional arguments in favour of the considerations presented here.

There is another proof of inequality (1) based on a weaker assumption, which consists not in the simultaneous existence of all four values a_0, a_1, b_0, and b_1, but only in the existence of all elementary four-dimensional probabilities $P(A_0, A_1, B_0, B_1)$ [15]. Indeed, assuming all of them to be nonnegative and giving unit in the sum proceeding from the normalisation condition for all possible probabilities of the experiment's outcome, and also representing the averages in (1), for example, as

$$P_{a_0b_0}(++) = (++++)+(+++-)+(+-++)+(+-+-),$$

we find that the sum of all averages in (1) is exactly equal to the doubled expansiom of unit, i.e., the double sum of all possible $P(A_0, A_1, B_0, B_1)$, from which, again, inequality (1) necessarily follows [15]. However, for (1) to be violated, it is sufficient that not all but *only some* of the values $P(A_0, A_1, B_0, B_1)$ do not exist.

Indeed, if we calculate the quantum averages of these elementary probabilities as applied to the case of measuring the polarisation state of an entangled pair of photons, as is the case in the experiment [4], only some of them will turn out to be negative [15], similarly to what happens in the Wigner distribution.

But what do these joint negative probability distributions mean? They relate observable values, some of which are described by noncommuting operators, for example, A_0 and A_1, in the case when (1) is violated [15]. Therefore, their direct measurements, as well as measurements of their probability distributions, are impossible. In this sense, such elementary probabilities are devoid of *operational* meaning, similarly to negative probabilities in general.

How did the authors of [4] manage to obtain contradictory and mutually exclusive results? Obviously, this happened because the average values of $\langle A_0B_0\rangle$ were different at different stages of the experiment. Indeed, when additional beam splitters are installed and all four observables are measured simultaneously, it is clear that they are all described by the commuting operators and inequality (1) cannot be violated. A violation can occur only if the operator of the observable A_0 at the first stage of the experiment does not commute with A_1 at the subsequent stages. A similar situation is observed with B_0 and B_1. If the observables are described by different operators at different stages of the experiment, it is clear that the observables themselves differ from each other.

It should be emphasised that two-particle states are used in the derivation of the usual Bell inequalities of the CHSH type. And these inequalities are formulated from the correlation functions $E(a, b)$, to calculate which it is necessary to perform a series of measurements, followed by the subsequent averaging of their results. These are the correlation functions that appear in Eqn (1). In the analysed experiment, six-particle states are used, which significantly distinguishes this situation from the usual consideration, since both the measurement protocol and the procedure for processing the results change. In particular, it is possible to obtain all four measured values in a single measurement. This is precisely the reason why the authors of the experiment [4] incorrectly used the Bell inequality of the CHSH type. From these simple considerations, it clear that the violation of Eqn (1) does not at all indicate the absence of both objectively existing A_0 and B_0, as well as the collapse of the original quantum state vector. Stronger arguments would have been required to prove this point.

4. Some general considerations

The very fact that it is possible to measure in a nondemolition way the presence or absence of a state vector collapse in a remote localised system raises some difficult questions. If the collapse occurs instantly (and there is experimental confirmation of this, at least, the collapse rate in [16, 17] exceeds c by several orders of magnitude), then, having the ability to produce such a measurement, I can instantly transmit information using a superlight telegraph, since the presence and absence of the collapse I can encode by dichotomous values corresponding to 1 bit. However, this is prevented by the so-called 'no communication theorem' [5], which is very general in nature, and therefore it seems unlikely to be violated.

Indeed, let us assume that in experiment [4] Alice and Bob conduct an interference experiment *before* their friends record an entangled pair of photons, i.e. before the collapse. Naturally, they would receive interference confirming its absence. But what if the collapse happens *before* Alice and Bob perform a measurement? In full accordance with the 'no communication theorem', *nothing* had to change; otherwise, they and their friends would have established an instantaneous superlight communication channel.

Thus, without even delving into the subtleties of the experiment and the features of the Bell inequality of the CHSH type, we can conclude that the denial of the existence of objective reality cannot be proved on the basis of Wigner friends' paradox.

It should also be noted that in the experiment [4], only simultaneous recording of all six photons by Alice, Bob, and their friends is considered informative, or, in other words, there is no remote observation of a localised quantum system of friends. But it is precisely such a nondemolition measurement that is supposed in Wigner friends' paradox. These considerations explain the possibility of obtaining different averages $\langle A_0 B_0 \rangle$ at different stages of the experiment [4] and should be taken into account when planning such experiments. Let us explain this with a particular example.

5. About a failed attempt of superlight communication

Attempts to implement superlight communication based on a remote nondemolition measurement of the instantaneous collapse of the state vector have been made repeatedly. In works [18–20], a scheme shown in Fig. 1 is proposed, which, it would seem, allows implementation of this opportunity. However, more detailed calculations, as shown below, indicate the opposite. We give them here because they are directly related to the issue of Wigner's nondemolition observation of his friend.

Consider the principle of the scheme operation. During a certain time interval, a pair of entangled photons is sent to observers A and B from a source of parametric scattering of biphotons, which is illuminated by laser pumping, i.e., the

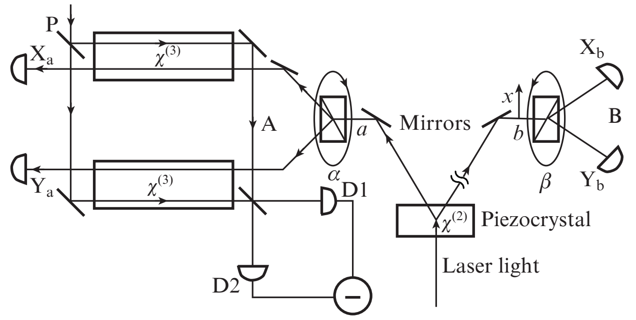

Figure 1. Diagram of an attempt by observer A to measure the moment of the state vector reduction as a result of a collapsing measurement by observer B. Observer A can use detectors X_a and Y_a to determine which of the detectors of observer B (X_b or Y_b) is triggered in the case of a collapsing measurement. In this case, it is important that observer A first makes a measurement using detectors D1 or D2, and only then using X_a or Y_a.

laser pumping falls on a piezocrystal, and a pair of entangled photons is born in it. One of them is sent to observer A, while the second one, to observer B. The photons are entangled in polarisation. Observers have polarising Wollaston prisms, to which photons are directed, i.e. each to his own prism. In principle, the polarisation state of these photons can be measured using X_b and Y_b detectors. But it is observer B who decides whether to perform such a measurement or not. If he has performed a measurement, then this event is assigned a unit value, and if not, to zero. The angles α and β of rotation of the Wollaston prisms are chosen the same, i.e. they are equally oriented in space relative to each other.

Then, the photon of observer A, divided into two channels, falls into a medium with cubic nonlinearity. The test photon P, also divided into two channels, is directed towards this photon and, for photon P, these channels are the Mach–Zehnder interferometer's arms. The test photon P exits the interferometer and is recorded by detectors D1 or D2. The difference scheme makes it possible to measure the cosine of the phase difference in the interferometer arms with allowance for nonlinear interaction of entangled and probe photons. After this measurement, observer A records the entangled photon using the detectors X_a or Y_a.

The physical principle of the scheme is based on the fact that the measurement (by observer B) of one of the photons of this pair leads to the collapse of the quantum state vector of the entire system of two entangled photons. The collapse occurs instantly, so observer A, equipped with an appropriate measuring system capable of recording this collapse (or its absence), will know about the actions of observer B almost instantly, no matter how far away it is located.

How does the observer's measuring system work? First of all, its actions should not collapse the superposition of the polarisation states of the entangled photon coming to it; otherwise, the information on the actions of observer B will be lost forever due to the 'no communication theorem' [5]. Therefore, its measurement should be nondemolition. On the other hand, it must somehow 'feel out' the entangled photon. In work [21], it was strictly proved (as, incidentally, in a number of other works) that before the collapse, the photon is present at once in both spatially separated channels corresponding to orthogonal polarisations. If we make these channels the Mach–Zehnder interferometer's arms, the photon will be present in both arms at once; otherwise, there will be no interference of single photons observed experimentally. After the collapse caused by the fact of measurement made by observer B, the photon will only be present in a single channel due to the collapse of the state vector of the entire system of two entangled photons.

Further, if nonlinear transparent media with cubic Kerr nonlinearity are installed in the interferometer channels, then observer A will want to determine whether the entangled photon coming to him is located in two arms or in a single one, without finding out in which particular arm it is located (otherwise, observer A will produce a collapsing measurement earlier than observer B, if he has not yet performed it). Thus, such a problem of nondemolition measurement, it would seem, can be solved by additional illumination of the interferometer by trial radiation that nonlinearly interacts with an entangled photon in the Kerr medium as a result of cross-interaction.

What is the result? By making a nondemolition measurement of the entangled photon, observer A could find out whether observer B has made a collapsing measurement or not, which is equivalent to transmitting a single bit of information from B to A.

6. Basic relations

We now consider the formal procedure for describing the system.

We take a pair of entangled photons correlated by polarisation. Their state vector is expressed as

$$|\psi\rangle = \frac{1}{\sqrt{2}}(|1\rangle_x^a|1\rangle_x^b|0\rangle_y^a|0\rangle_y^b + |0\rangle_x^a|0\rangle_x^b|1\rangle_y^a|1\rangle_y^b). \tag{3}$$

Here $|1\rangle$ are the single-photon Fock states; $|0\rangle$ is vacuum; superscripts a and b refer to the first and second photons of the entangled pair, respectively; and mutually orthogonal transverse directions (subscripts x and y) determine orthogonal polarisation directions. The structure of this state vector is such that, although the polarisation directions x and y of each of the photons a or b of the pair are equally probable, they are strictly correlated with each other, since their polarisation planes always coincide during recording. Such states are usually prepared using parametric light scattering (see, for example, [22–25] and references therein).

Let us direct each of the photons of the pair to the Wollaston prism, which divides the mutually orthogonal polarisations into two separate channels. In fact, it works as a beam splitter and for photons with absolutely random polarisation, as a 50% beam splitter.

Now we proceed to the nondemolition measurement of the first photon. In both output channels, after the Wollaston prism, we set media with cubic nonlinearity in which self-phase modulation (SPM) takes place. Since the operator $\hat{n}(t)$ in SPM is a time invariant, the number of photons in SPM is a nondemolition observable and can be measured in a nondemolition way. Let us send to the inputs of nonlinear media with cubic nonlinearity (for example, quartz fibres), in addition to the measured signals, also weak probe modes p_1, p_2 of equal average intensity, and by measuring the phase difference of which, we will try to determine whether the first photon a is in a superposition state before the 'strong' collapsing measurement of the second photon b, or in one of the channels after reduction as a result of such a measurement.

Let us use the single-photon Fock state $|1\rangle^{\rm p}$ as a probe mode. After a 50% beam splitter, a superposition is formed

$$|\psi_{\rm p}\rangle = \frac{1}{\sqrt{2}}\big(|1\rangle_1^{\rm p}|0\rangle_2^{\rm p} + |0\rangle_1^{\rm p}|1\rangle_2^{\rm p}\big),$$

where indices 1 and 2 denote the interferometer arms.

The quantum state of the system as a whole, after the production of a pair of entangled photons and their separation by polarising prisms for observers A and B, is described by a pure state with a vector

$$|\psi_{ab\rm p}\rangle = {}^1\!/_2[(|1\rangle_1^a|1\rangle_1^{\rm p}|0\rangle_2^a|0\rangle_2^{\rm p} + |1\rangle_1^a|0\rangle_1^{\rm p}|0\rangle_2^a|1\rangle_2^{\rm p})|1\rangle_x^b|0\rangle_y^b$$
$$+ (|0\rangle_1^a|1\rangle_1^{\rm p}|1\rangle_2^a|0\rangle_2^{\rm p} + |0\rangle_1^a|0\rangle_1^{\rm p}|1\rangle_2^a|1\rangle_2^{\rm p})|0\rangle_x^b|1\rangle_y^b]. \tag{4}$$

The impact of the nonlinearity χ described by the operator $\hat{U} = \exp(-{\rm i}\chi_{a\rm p}\hat{n}_a\hat{n}_{\rm p}/2)$ in the case of cross-interaction (see, for example, [18] and references therein) gives

$$|\psi'_{ab\rm p}\rangle = {}^1\!/_2[(|1\rangle_1^a|1\rangle_1^{\rm p}|0\rangle_2^a|0\rangle_2^{\rm p}\exp(-{\rm i}\bar{\chi}_{a\rm p1}/2)$$
$$+ |1\rangle_1^a|0\rangle_1^{\rm p}|0\rangle_2^a|1\rangle_2^{\rm p})|1\rangle_x^b|0\rangle_y^b + (|0\rangle_1^a|1\rangle_1^{\rm p}|1\rangle_2^a|0\rangle_2^{\rm p}$$
$$+ |0\rangle_1^a|0\rangle_1^{\rm p}|1\rangle_2^a|1\rangle_2^{\rm p}\exp(-{\rm i}\bar{\chi}_{a\rm p2}/2))|0\rangle_x^b|1\rangle_y^b]. \tag{5}$$

In the Heisenberg representation, the action of the beam splitter located in front of the difference scheme detectors is described as $\hat{a}'_{\rm p} = (\hat{a}_1^{\rm p} \pm \hat{a}_2^{\rm p})/\sqrt{2}$. The plus sign here corresponds to detector D1, while minus, to D2. Then we obtain that the average number of photocounts of detector D1 is

$$\frac{1}{4}\Big(2 + \cos\frac{\bar{\chi}_{a\rm p1}}{2} + \cos\frac{\bar{\chi}_{a\rm p2}}{2}\Big),$$

and that of D2 is

$$\frac{1}{4}\Big(2 - \cos\frac{\bar{\chi}_{a\rm p1}}{2} - \cos\frac{\bar{\chi}_{a\rm p2}}{2}\Big).$$

In the Schrödinger representation, the quantum state of the system at the output of the Mach–Zehnder interferometer after the output beam splitter is described by the vector

$$|\psi''_{ab\rm p}\rangle = \frac{1}{2\sqrt{2}}\{[|1\rangle_1^a|0\rangle_2^a|1\rangle_x^b|0\rangle_y^b[\exp(-{\rm i}\bar{\chi}_{a\rm p1}/2) + 1]$$
$$+ |0\rangle_1^a|1\rangle_2^a|0\rangle_x^b|1\rangle_y^b[1 + \exp(-{\rm i}\bar{\chi}_{a\rm p2}/2)]]|1\rangle_1^{\rm d}|0\rangle_2^{\rm d}$$
$$+ [|1\rangle_1^a|0\rangle_2^a|1\rangle_x^b|0\rangle_y^b[\exp(-{\rm i}\bar{\chi}_{a\rm p1}/2) - 1]$$
$$+ |0\rangle_1^a|1\rangle_2^a|0\rangle_x^b|1\rangle_y^b[1 - \exp(-{\rm i}\bar{\chi}_{a\rm p2}/2)]]|0\rangle_1^{\rm d}|1\rangle_2^{\rm d}\}. \tag{6}$$

Here, $|1\rangle_1^{\rm d}|0\rangle_2^{\rm d}$, $|0\rangle_1^{\rm d}|1\rangle_2^{\rm d}$ are the states at the input of the detectors located in front of the difference scheme at the bottom of Fig. 1, with $|1\rangle_1^{\rm d}|0\rangle_2^{\rm d}$ and $|0\rangle_1^{\rm d}|1\rangle_2^{\rm d}$ – D2 corresponding to the triggering of detectors D1 and D2, resepectively. It is seen that when one of them is triggered, i.e., when expression (6) is reduced to its two upper or lower rows, the superposition $|\psi_b\rangle = (1/\sqrt{2})(|1\rangle_x^b|0\rangle_y^b$ is not reduced to one of the components of this state, which is expressed in the fact that, in general case, $|1\rangle_x^b|0\rangle_y^b$, и $|0\rangle_x^b|1\rangle_y^b + |0\rangle_x^b|1\rangle_y^b)$ is present in each of the rows of (6). Thus, such a measurement is truly a nondemolition one. In this case, it is important that the numerical coefficients in (6) are not zero. It is best that they are equal in absolute value. In this case, the measurement made by D1 or D2 detectors are completely free of information about which channel contains a photon of the entangled pair. Previous results with cosines also follow easily from expression (6).

What happens when observer B produces a collapsing measurement of the polarisation state? The $|\psi''_{abp}\rangle$ state reduces either to the first and third rows of (6), or to the second and fourth. In this case, the probabilities of triggering the detectors are either $^1\!/_2(1 \pm \cos\bar{\chi}_{ap1}/2)$, or $^1\!/_2(1 \pm \cos\bar{\chi}_{ap2}/2)$, where, as above, the plus sign corresponds to detector D1, while the minus sign corresponds to detector D2. Thus, a pure state transits into a mixed state with equal probabilities (1/2) of both outcomes. This means that the measurement results do not allow us to distinguish the pure state $|\psi''_{abp}\rangle$ from the mixed state with the probability $^1\!/_2(1 \pm \cos\bar{\chi}_{ap1}/2)$ or $^1\!/_2(1 \pm \cos\bar{\chi}_{ap2}/2)$ after the 'strong' collapsing measurement performed by observer B, since averaging these probabilities, i.e. summing them with a weight of 1/2, gives the same probability as in the absence of a collapsing measurement by observer B.

Consider the last opportunity that may lead to the desired goal. We perform another subsequent measurement by observer A using additional detectors X_a, Y_a located in the leftmost part of Fig. 1, the implementation of which will allow us to determine which of the detectors of observer B (X_b or Y_b) triggered if it performed a collapsing measurement. Tentatively, it is necessary to set the nonlinear phase delays at which $\cos\bar{\chi}_{ap1}/2$ and $\cos\bar{\chi}_{ap2}/2$ differ from each other, and herewith, the numerical coefficients in all four summands in (6) are equal in modulus. This is achieved with $\cos\bar{\chi}_{ap1}/2 = +\sqrt{2}/2$ and $\cos\bar{\chi}_{ap2}/2 = -\sqrt{2}/2$ (or vice versa). In this case, triggering detectors D1, D2 located in front of the difference scheme in the lower part of Fig. 1 is probabilistically related to triggering detectors X_a and Y_a, if, of course, a collapsing measurement has been previously performed by observer B. And if not, these triggerings will be random. Thus, if those detectors are triggered that do not comply with the probability law $^1\!/_2(1 \pm \cos\bar{\chi}_{ap1}/2)$, provided one of the additional detectors (X_a) of observer A is triggered, or do not comply with the probability law $^1\!/_2(1 \pm \cos\bar{\chi}_{ap2}/2)$, provided another detector (Y_a) is triggered, then observer A may conclude that observer B has not performed a collapsing measurement. However, as calculations show, the probability laws are the same in both cases, although the presence and absence of collapse, as shown above, requires different calculation algorithms, which we have reproduced.

This example shows how a seemingly well-founded scheme of nondemolition measurement of the collapse of the state vector of a remote localised system fails due to the 'no communication theorem'.

7. Conclusions

What conclusion can be drawn from the above argumentation? Does it prove the inconsistency of the informational interpretation of quantum mechanics? Not at all. But if it were possible to prove the absence of objective reality in relation to the wave function and state vector, then all other interpretations would have to be archived. However, as follows from the above, this would be premature. Informative interpretation remains only one of the contenders along with other consistent concepts [26–33].

But is Wigner friends' paradox, in principle, so insoluble within the framework of the traditional quantum-mechanical description? It seems to me that this paradox does not require any fundamentally new approach and a radical change in the concepts of the objectivity of quantum processes and measurement results. In fact, Wigner's friend produced a collapsing measurement and quite correctly described it using von Neumann's projection postulate. Wigner himself considers the entire experimental setup of the friend, including his meter, as a single quantum system. In this case, there is no need to expose the measurement process to the action of the projection postulate; we should simply consider it within the framework of the decoherence phenomenon [34, 35]. Thus, the same measurement result is obtained in different ways, which exhausts the entire paradoxicality of the situation.

Thus, remote nondemolition measurement of the collapse of the state vector of a quantum system of two entangled particles is impossible, and the objectivity of the measurement results has not been disproved, at least by known methods.

Acknowledgements. The work has been supported by the Russian Foundation for Basic Research (Grant No. 18-01-00598A).

References

1. Bohr N. *Phys. Rev.*, **48**, 696 (1935).
2. Brukner C., Zeilinger A. *Acta Phys. Slovaca*, **49**, 647 (1999).
3. Brukner C., Zeilinger A. *Phys. Rev. Lett.*, **83**, 3354 (1999).
4. Proietti M., Pickston A., Graffitti F., et al. *Science Advances*, **5** (9), eaaw9832 (2019); DOI: 10.1126/sciadv.aaw9832.
5. Peres A., Termo D.R. *Rev. Mod. Phys.*, **76**, 93 (2004).
6. Clauser J., Horne M., Shimony A., Holt R. *Phys. Rev. Lett.*, **23**, 880 (1969).
7. Aspect A., Grangier P., Roger G. *Phys. Rev. Lett.*, **47**, 460 (1981).
8. Aspect A., Grangier P., Roger G. *Phys. Rev. Lett.*, **49**, 91 (1982).
9. Aspect A., Dalibar J., Roger G. *Phys. Rev. Lett.*, **49**, 1804 (1982).
10. Aspect A., in *Quantum [Un]speakables – From Bell to Quantum Information*. Ed. by R.A. Bertlmann, A. Zeilinger (Springer, 2002).
11. Bell J.S. *Physics*, **1**, 195 (1964).
12. Belinsky A.V., Klyshko D.N. *Usp. Fiz. Nauk*, **163** (8), 1 (1993).
13. Belinsky A.V., Klyshko D.N. *Phys. Lett. A*, **176** (6), 415 (1993).
14. Greenberger D.M., Horn M.A., Shimony A., Zeilinger A. *Am. J. Phys.*, **58**, 1131 (1990).
15. Belinsky A.V. *Usp. Fiz. Nauk*, **164** (4) 435 (1994).
16. Gisin N. *Quantum Chance: Nonlocality, Teleportation and Other Quantum Marvels* (Berlin: Springer, 2014).
17. Salart D., Baas A., Branciard C., Gisin N., Zbinden H. *Nature*, **454**, 861 (2008); DOI:10.1038/nature07121.
18. Belinsky A.V., Zhukovskiy A.K. *Vest. Mosk. Univer. Ser. 3. Fiz., Astronom.*, (5), 21 (2016).
19. Belinsky A.V. *Elektron. Tekh. Ser. 3. Mikroelektron.*, No. 3 (171), 94 (2019).
20. Belinsky A.V. *Vest. Mosk. Univer. Ser. 3. Fiz., Astronom.*, (6), 127 (2017).
21. Belinsky A.V. *Vest. Mosk. Univer. Ser. 3. Fiz., Astronom.*, (4), 12 (2018).
22. Klyshko D.N. *Photons and Nonlinear Optics* (Boca Raton: CRC Press, 1988).
23. Lariontsev E.G. *Quantum Electron.*, **45**, 121 (2015) [*Kvantovaya Elektron.*, **45**, 121 (2015)].
24. Kovlakov E.V., Bobrov I.B., Straupe S.S., Kulik S.P. *Phys. Rev. Lett.*, **118**, 030503 (2017).
25. Belinsky A.V. *Kvantovye izmereniya* (Quantum Measurements) (M.: BINOM. Laboratoriya znanii, 2015).

26. Frauchiger D., Renner R. *Nature Commun.*, **9**, 3711 (2018).
27. Lazarovici D., Hubert M. *Sci. Rep.*, **9**, 470 (2019).
28. Sudbery A. *Found. Phys.*, **47**, 658 (2017).
29. Pusey M.F. *Nature Phys.*, **14**, 973 (2018).
30. Andreev V.A. *Teor. Mat. Fiz.*, **158** (2), 234 (2009).
31. Andreev V.A. *Teor. Mat. Fiz.*, **152** (3), 488 (2007).
32. Andreev V.A., Man'ko V.I., Man'ko O.V., Shchukin E.V. *Teor. Mat. Fiz.*, **146** (1), 172 (2006).
33. Andreev V.A., Man'ko V.I. *Teor. Mat. Fiz.*, **140** (2), 284 (2004).
34. Mensky M.B. *Usp. Fiz. Nauk*, **168** (9), 1017 (1998).
35. Zurek H.W. *Los Alamos Science*, (27), 1 (2002).