Chapter

Quantum Dots CdSe/ZnS as a Source Array of Entangled States

Anatolii Isaev

Abstract

A quantum dot is a quantum system in classical space with unique characteristics, as a result of a large quantum limitation. The experimental results of this chapter substantiate the ability of quantum dots to play a key role in purely quantum processes, for example, teleportation of quantum objects, and the generation of macroscopic quantum gravity force and, of course, are a qubit in quantum computing. A quantum dot has the ability to capture (capture) a photo-induced charge carrier by a surface defect of its crystal structure and, thereby, create a second stable long-lived quantum state, which is a necessary requirement for a qubit. This ability puts a quantum dot out of competition with respect to many other quantum objects, like qubits, in terms of the simplicity and cheapness of their continuous generation in standard laboratory conditions. Quantum dots have received wide recognition because of their unique exciton luminescence characteristics; this chapter substantiates a fundamentally new area to use quantum dots in the development and study of both fundamental and applied physics.

Keywords: quantum dots, metastable excitons, qubit, quantum entanglement

1. Introduction

Semiconductor quantum dots (QDs), for example, CdSe/ZnS is an attractive quantum object in classical space. Attractiveness is based on the unique characteristics of nanoscale structures with a large quantum limitation. The high quantum yield of exciton luminescence (up to 80%), the narrow band of this luminescence, the long photo stability and the rearrangement of the exciton luminescence band in a wide spectrum range, depending on the size of the nanoparticles, have specific unique characteristics of these crystalline nanostructures [1]. These characteristics provide potential applications in photovoltaic and laser devices, thin-film transistors, light-emitting diodes and luminescent labels in biology and medicine [2–6]. In this article, I want to justify no less, but rather more, meaningful applications, both in fundamental and in applied physics.

We are talking about the properties of crystalline structures to have on their surface quantum defects called surface trap states. These surface traps capture photo-induced charge carriers, usually an electron, and delay its recombination for a fairly long time [7–9]. In [10], the exciton luminescence of CdSe/ZnS QDs was recorded in the millisecond time range and its intensity was six orders of magnitude less than the intensity of exciton luminescence immediately after the photo excitation pulse. Such a quantum state with a long existence of an exciton is called a metastable exciton. A metastable exciton is an electron—hole pair, in which an electron is captured by a surface trap with a long lifetime [10].

The typical relaxation time of exciton luminescence is the nanosecond time range. Consequently, relaxation of all excited quantum states of QDs takes place in the nanosecond range, whereas relaxation of metastable excitons takes place in the millisecond range, which is six orders of magnitude greater than the lifetime of all other quantum states of QDs. In other words, QDs with a metastable exciton are a quasistable quantum state, and can play the role of a second stable state $|1\rangle$ of QDs, as a qubit. The first stable state of such a qubit $|0\rangle$ is QD in the ground quantum state. The irradiation of a colloid QDs is a simple and practically free way to continuously generate an array of qubits in two stable quantum states, naturally, when the energy of the optical beam quanta exceeds the QD bandgap.

Obviously, we must receive the result of any quantum process, for example, quantum computing or teleportation in the classical space, in the space where we all function. For example, a digital computer operates in its "digital space." We will need it only when it "produces" a result that is understandable to us, for example, a graph or a picture, but not as a set of numbers. QDs with a metastable exciton, as a qubits in the quantum state $|1\rangle$, have unique nonlinear optical characteristics. The fact is that the electron capture by the surface trap separates the charge carriers by a distance that coincides with the size of the QD, which are several nanometers. Such a large separation of charge carriers is the source of a very large light-induced dipole moment $\boldsymbol{p}$ of an individual QD with a metastable exciton. The dipole moment $\boldsymbol{p}$ is responsible for the value of light-induced change in the refractive index [11]. Therefore, a large value of $\boldsymbol{p}$ makes it possible to record the distribution of the concentration of individual QDs with a metastable exciton using conventional interferometry. It is this distribution of the concentration of QDs in the quantum state that is the result of the quantum process in the quantum space, which is the "quantum box" by definition of the founding fathers of quantum mechanics.

We see that quantum dots can be in two stable quantum states, which allows them to be used as a qubit in all modern quantum technologies. One of these quantum states has a significantly different classical refractive index. This property makes it possible to register individual QDs in this quantum state $|1\rangle$ by interferometry methods and, thus, to register the results of quantum processes in classical space. The experimental results of this chapter substantiate and realize this possibility, which opens up new areas for the use of quantum dots in fundamental and applied physics.

2. Teleportation of CdSe/ZnS QDs in the classical space

2.1 Quantum entanglement

Quantum entanglement is a new resource of quantum physics, the same as, for example, energy [12]. New resources make it possible to discover new potentials and implement fundamentally new processes of quantum physics. The modern representation of quantum states is based on the statement that, in quantum mechanics, any physical system is described completely by a state vector $|\Psi\rangle$ in the Hilbert space H. A system with a two-dimensional Hilbert space is called a qubit (quantum bit). For several Hilbert spaces, for example, for H_A and H_B, the complete Hilbert space is the tensor product of the subsystem spaces: $H_{AB} = H_A \otimes H_B$. Any quantum system that is described by a single state vector is a pure state. Next, the density operator and other mathematical transformations are introduced. Everything, all Physics is over! Mathematics on paper remained only!

A real qubit is a quantum object that has two stable quantum states, which, as a rule, have different easily measured classical characteristics. For example, a quantum of light in the "*o*" and "*e*" states of polarization, or a neutral atom and a charged ion of this atom. And these characteristics are measured easily using classic devices. The modern representation of quantum entanglement is based on the modern representation of quantum states. A quantum state $|\Psi\rangle$ is entangled if it cannot be written as a tensor product, i.e., $|\Phi\rangle \neq |a\rangle \otimes |b\rangle$. And, here, if the quantum state is written as the sum of tensor products, then this state is entanglement.

$$|\Phi\rangle = \frac{1}{N}\left(|a_1\rangle \otimes |b_1\rangle + |a_2\rangle \otimes |b_2\rangle\right) \tag{1}$$

As an example, a type of state is usually given

$$|\Phi\rangle = \frac{1}{\sqrt{2}}\left(|01\rangle - |10\rangle\right) \tag{2}$$

The term "entanglement" was introduced by Schrödinger for the first time in 1935 [13]. Schrödinger introduced this term to describe the specific relationship between quantum systems, which have correlations between their dynamic quantities: position and momentum. And this relationship is expressed in an infinite set of dynamic values of two particles. Thus, Schrödinger justified one of the key properties of quantum entanglement—the complete uncertainty of the values of classical dynamic quantities such as the position and momentum of a particle. And what do we see in Eq. (2)? Here, the quantum state $|\Phi\rangle$ of a quantum superposition of one object in two basic states is written, $|0\rangle$ and $|1\rangle$ decoherence of which will give an equiprobable (1/2) result to find this object, both in the state $|01\rangle$ and in the state $|10\rangle$. Where is the uncertainty here? Complete uncertainty reflects the form of writing a quantum state $|\Psi\rangle$ quantum superposition.

$$|\Psi\rangle = \alpha\,|0\rangle + \beta\,|1\rangle, \tag{3}$$

where α and β are complex numbers, the sum of squares of which $|\alpha|^2 + |\beta|^2 = 1$. In essence, $|\alpha|^2$ and $|\beta|^2$ are probabilities of obtaining a state of $|0\rangle$ or $|1\rangle$ in classical space as a result of decoherence. To feel that there is entanglement you can simply imagine the coin that was thrown up, and it falls and rotates. While the coin is rotate, it is impossible to say what condition it is in. The coin is in a completely indefinite state, but it is exact in some of the states $|0\rangle$ or $|1\rangle$. The coin fell to the ground and here it can be said, determined or measured in which particular state and in which particular place on the earth. Some people write in their articles that a quantum object in a state of quantum superposition is simultaneously in all its basic states. But this is nonsense. A quantum object cannot be simultaneously in its two states, but to be in an uncertain state, there are no problems here.

Thus, we conclude that the quantum state $|\Psi\rangle$ in the entry form (3) is a quantum superposition, and it is an entangled quantum state. The principle of quantum superposition states that the linear combination of quantum states of all quantum objects of the participants of this superposition is also a quantum state. The linear combination provides an exponential growth of quantum states of quantum objects with two basic states (qubit) with a linear increase in the number of these qubits. This means that N quits provide 2^N entangled quantum states of quantum superposition. And if we return to physics, this means that the wave function of the state $|\Psi\rangle$ contains 2^N entangled wave functions. If N qubits occupy a macroscopic volume, then the wave function of state $|\Psi\rangle$ is macroscopic. This is a fundamental conclusion, since the macroscopic wave function is the basis of all quantum processes as a result of Bose-Einstein condensation. The way to create a Bose-Einstein condensate regardless of temperature opens up fantastic prospects for practical devices based on quantum effects. This is one of the physical resources of quantum entangled states.

2.2 Experimental implementation of multi-particle quantum superposition

Obviously, practical applications make sense with an array of entangled quantum states, the source of which is quantum superposition. Qbits are quantum objects in two basic states, the dynamic characteristics of which, for example, their location, can be easily measured in classical space. It is these qubits, more precisely, their quantum states $|0\rangle$ and $|1\rangle$ that form the quantum state of many-particle quantum superposition $|\Psi\rangle$ in the self-assembly mode. Self-assembly is a typical process of quantum physics, a typical example is Bose-Einstein condensate. Another typical example is the self-assembly of nanoscale quantum objects with a large quantum confinement [14]. Practical devices require qubits cheap and easily accessible. In addition, such qubits must function under normal conditions: they do not require ultrahigh vacuum or ultralow temperatures.

The semiconductor quantum dots (QDs) of CdSe/ZnS were used in this work as such qubits. The modern concept of quantum entanglement asserts that quantum entanglement is a consequence of some nonlocality of quantum mechanics, which cannot be explained from the standpoint of classical physics [15]. This concept is the basis for research on quantum communications, quantum cryptography and quantum networks. Let us leave the question of nonlocality "for later," and let's discuss the obvious property of quantum entanglement, which is it's decoherence. An array of tossed and rotating coins will fall to the ground. Each coin will fall on one of its sides. This particular side of the coin is the result of the interaction of all the coins, both among themselves and with external and internal forces, as they rotate. Decoherence of quantum superposition unravels all entangled quantum states into concrete quantum states $|0\rangle$ and $|1\rangle$ of each qubit in classical space and, thus, makes it possible to record the result of the interaction of forces in quantum superposition or quantum entanglement.

The dynamic principle of quantum superposition states that the quantum state of quantum superposition can occur again after decoherence, if conditions for this exist. Therefore, the continuous functioning of the states of quantum superposition according to the scheme "self-assembly of quantum superposition—decoherence under the influence of external and internal forces—self-assembly of quantum superposition again—decoherence again, etc." can occur only with continuous generation of the qubit. The quantum state of the qubit $|0\rangle$ is the ground unexcited state, which does not require external influence for its existence. The quantum state of the qubit $|1\rangle$ is a QD with a metastable exciton. Therefore, the continuous generation of this state is a necessary condition for the continuous functioning of the quantum state of quantum superposition. An optical beam with quantum energy greater than the bandgap is the driving force that is able to generate the state $|1\rangle$ continuously.

An optical beam with a wavelength of λ = 437 nm was used for this in experiments. A CW-laser was used as a source of this beam with a power of 30 mW. The scheme and methodology of the experiment are presented in detail in [16]. Here, we will focus on key phenomena that characterize quantum entanglement as a truly new resource with fundamentally different possibilities of practical application. In short, the experiment consisted in observing and registering the trace profile of an optical beam that spread through a suspension of CdSe/ZnS quantum dots. The fact is that the pattern of the beam trace profile is a pattern of wave aberrations of a light-induced lens [17, 18], which occurs in a QDs suspension, as a result of the self-action of an optical beam, which generates a $|1\rangle$ quantum state with a different refractive index compared to the refractive index quantum state $|0\rangle$. The dynamic pattern of wave aberrations of a light-induced lens reflects the dynamics of the space-time redistribution of the wave surface of a light-induced change in the refractive index. The wave surface of the light-induced refractive index is the space-time distribution of the concentration of QDs in the quantum state $|1\rangle$. Thus, registration of the redistribution of the refractive index makes it possible to measure the redistribution of the concentration of the quantum state $|1\rangle$ (QD with a metastable exciton), including as a result of the presence of such QDs in the quantum state of quantum superposition. This is the "highlight" of the experiment. The fact is that decoherence of an array of entangled quantum states in quantum space, which is a "quantum box," as defined by the founding fathers of quantum mechanics, occurs under the influence of all forces, internal and external. Including those forces, the existence of which we do not know. Thereby, the registration of the result of decoherence of quantum superposition makes it possible to detect these forces and understand their physical nature.

2.3 Experimental implementation of teleporting CT CdSe/ZnS

All the experimental results were obtained in a simple experiment, the scheme of which is shown in **Figure 1a**. This graphic also shows a typical beam trace profile pattern on a remote screen. **Figure 1b** shows a typical transformation of the pattern of the beam trace profile after the start of illumination. Here, the time of 0 ms is the beginning of the illumination of the QDs suspension, and the intensity distribution is the input beam profile without a cuvette with a suspension with QDs in the beam. The input beam parameters were: beam convergence angle θ = 5.45 10^{-3}; $w_0 = \lambda/\pi\theta$ = 28 μm; $I_0 = 2P_l/\pi w^2$ = 2436 W/cm^2; $z_0 = \pi w_0^2/\lambda$ = 5.2 = 5.2 mm. The thickness of the cuvette with colloid was 5 mm.

Quantum teleportation is the concept of quantum physics, which is being studied in a large number of recent published works. The main research topics are quantum communication, quantum computing and quantum networks. The term teleportation means the process by which bodies and objects are transferred from one place to another without moving along any path. The "quantum teleportation" boom begins with article [19], in which an unknown quantum state is first measured and then reconstructed at a remote place. The implementation of this information protocol requires a classical communication channel [19], and quantum entanglement [12]. The conceptual basis of such a quantum teleportation is the assertion that two quantum particles in an entangled state have some non-locality so that changes in the state of one particle immediately correlate with changes in the remote system regardless of the signal passing time between them [15]. If this concept is accepted as a physical reality, then one should assume the existence of some otherworldly forces, which, and only they, provide such a speculative correlation between remote quantum objects. This article substantiates another concept of quantum teleportation, which is really a physical reality, since this concept is the result of an experiment.

The meaning of the experiment was to look the transformation of the pattern of the beam trace profile when moving the cuvette with the QDs colloid on a rough surface, as a result of which, the QDs colloid was subjected to micro-shaking. **Figure 2** contains information about how the dimensions of the pattern of the beam trace profile change in the process of establishing a steady state and after the beginning of the movement of the cuvette with the colloid QDs. These data were obtained at the position of the cuvette along the axis $Z = -15z_0$. Here D_{hor}, R_{dw} R_{up} is the horizontal diameter, the radius of the lower half and the radius of the upper half of the pattern of the beam trace profile. The time τ is the characteristic time of exponential relaxation of processes that control the pattern of the beam trace profile during the accumulation of QDs and the establishment of a steady state. The beginning of the movement of the cuvette with colloid took place after 3 seconds of illumination.

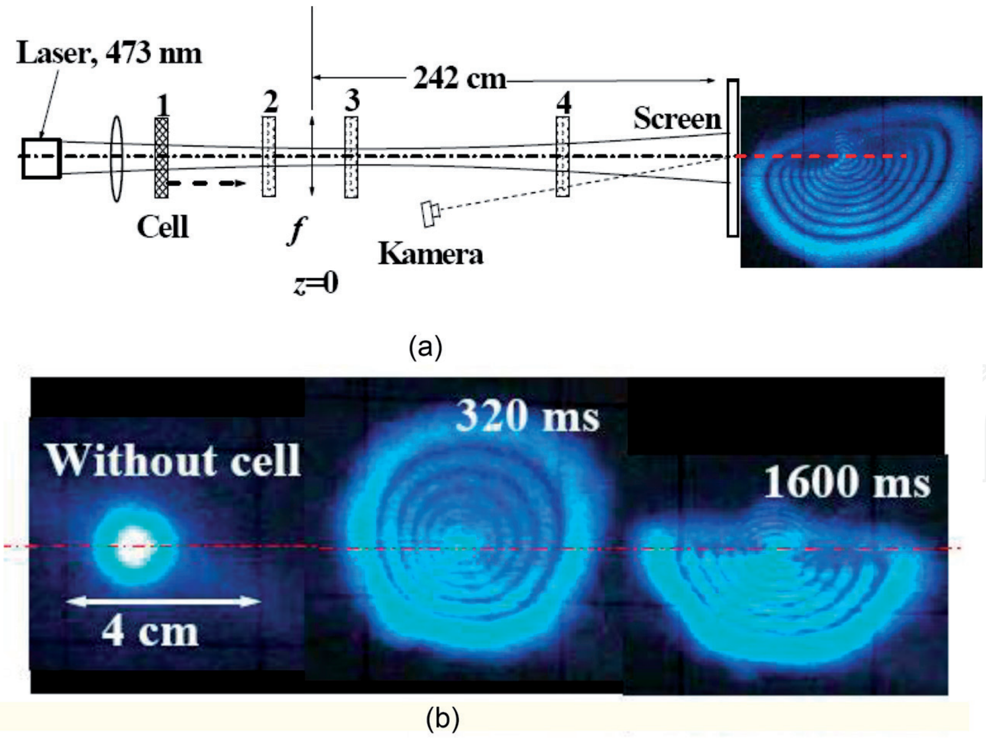


Figure 1.
(a) The scheme of the experiment and the profile of the laser beam trace on the screen. (b) The trace profile of the input optical beam and the trace profiles of the output beam in the process of accumulation of long-lived QDs after the start of illumination, $z = -29z_0$.

It is obvious that the establishment of a stationary state takes place as a result of at least two processes. The first ~400 ms there is an increase in all sizes of the pattern of the beam trace profile. Then, we see a dramatic change in the size behavior of this pattern. An obvious reduction in all sizes of this pattern is observed. We should note that the increase and subsequent reduction in the size of the pattern is well extrapolated by exponential functions. Moreover, the pattern of the upper half of the beam trace profile is reduced to a much greater degree and significantly sooner. We will analyze these experimental results below. Here, we will consider the situation after the beginning of the movement of the cuvette with the colloid to another location along the Z axis. Individual frames of the pattern transformation are shown in **Figure 3**. The real transformation of the pattern in real time is in the video files "trans1-trans3."

The beginning of this movement took place after 3 seconds of continuous illumination. Obviously, the steady state was achieved during this time (see **Figure 2**). This movement caused a complete "whistleblower" or "orgy" of the dimensions of the beam trace profile pattern, which **Figures 2** and **3** demonstrate quite well. We must note that the pattern of the profile of a beam trace changes its structure in an abrupt manner. Details of the pattern of each frame in **Figure 3** do not coincide with the details of the pattern of the previous frame of the video. All patterns of each frame change their details "jump." Recall that the time between frames was 40 ms. Here we should especially note that all the processes that controlled the size of the pattern immediately before the beginning of the displacement had characteristic relaxation times of 200–300 ms, which significantly exceeded the actual time of a cardinal change of the pattern itself.

Another key result is that the axis of the output optical beam coincides with the axis of the input optical beam with all the "manipulations" with the cuvette with a colloid: its movement along the Z axis ($\pm 49z_0$); micro-shaking due to the unevenness of painting the surface of the table on which the table with the cuvette was moving. Here we note that the cuvette was oriented at a small angle to the axis of the

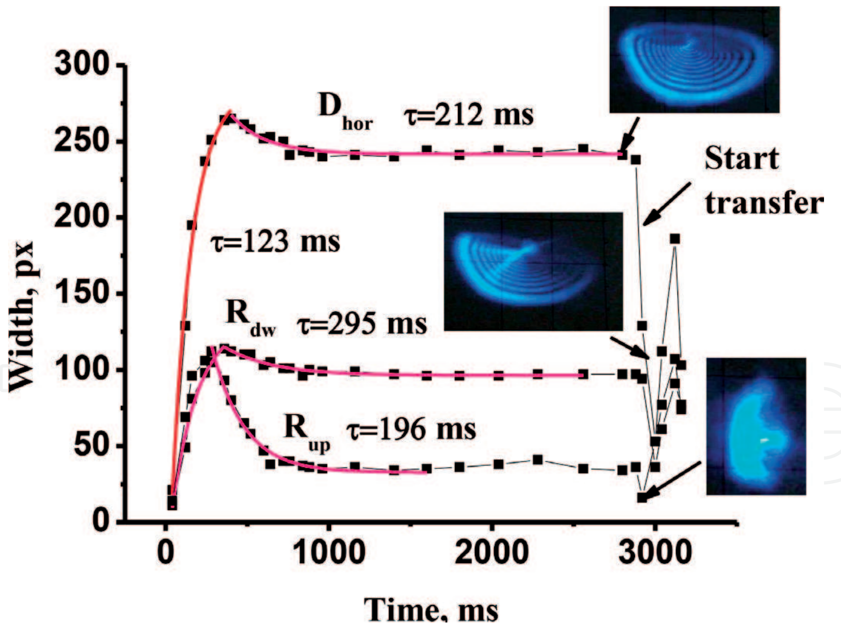


Figure 2.
The establishment of a stationary beam trace profile pattern. The inserts show the direct transformation of the pattern after the beginning of the movement from the position along the axis Z = $-15z_0$ to the side closer to the waist of the focused beam.

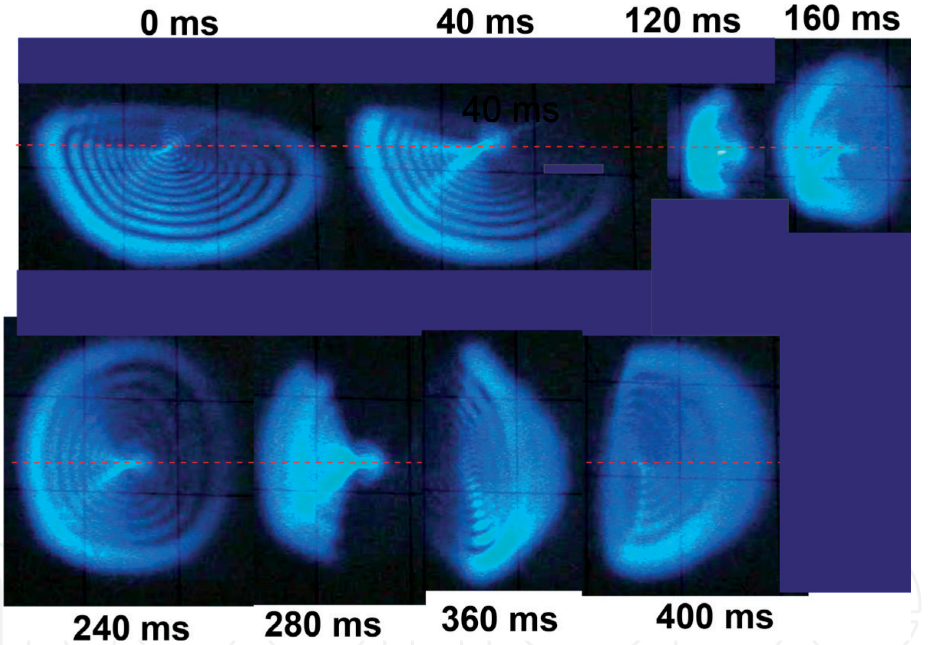


Figure 3.
Transformation of the pattern of the beam trace profile during the movement of the colloid from the position $z = -15z_0$.

input optical beam, and the axis of direct movement of the cuvette did not coincide with the axis of the input optical beam.

The pattern of the beam trace profile changes its structure and dimensions "abruptly" in each frame of the video. **Figure 4** shows how the digital profile of the beam trace profile pattern changes its structure and size after the beginning of the displacement (0 ms) of the cuvette along the z axis and after 120 ms. Here we have to remind that the beginning of movement took place after 3 seconds of continuous illumination, when the pattern of the beam trace profile was in a steady state with a characteristic exponential relaxation time τ ~200–300 ms.

Figures 2–**4** contain information that shows that the micro shake of a QDs colloid transforms the pattern of the beam trace profile over a time that is significantly

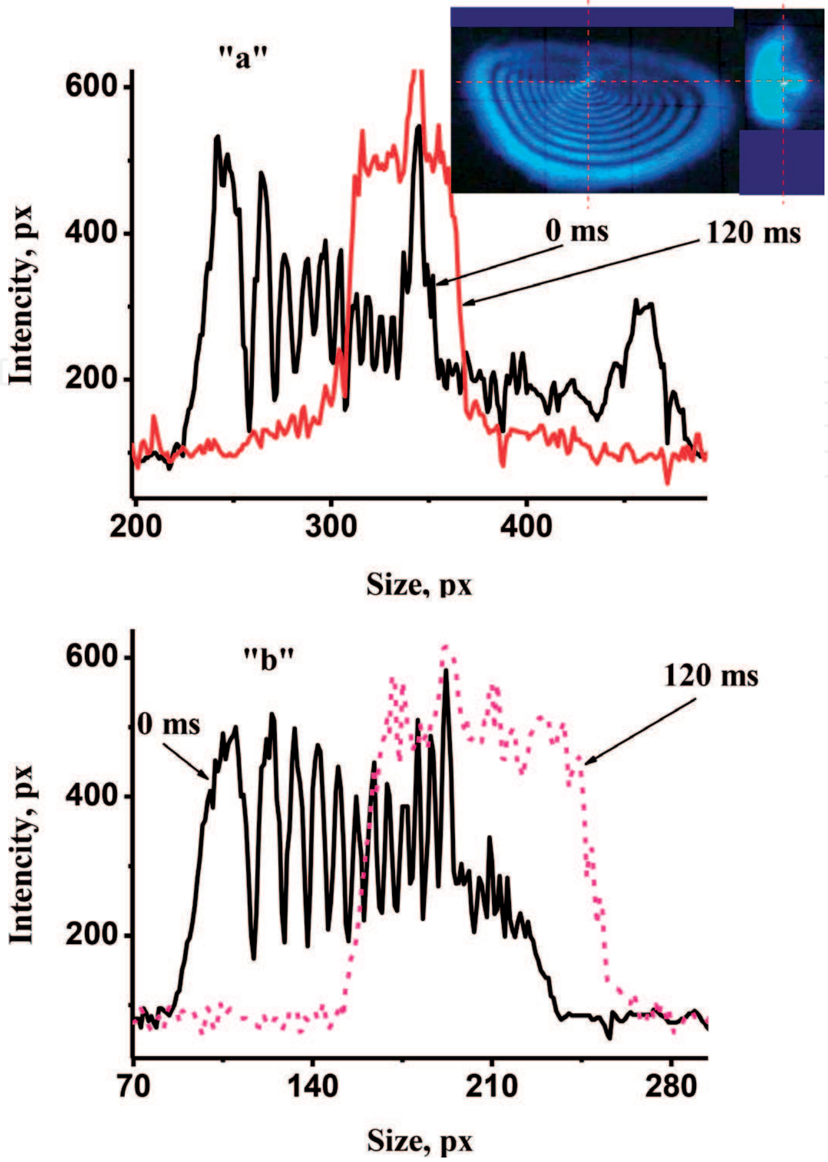


Figure 4.
Digital profile of horizontal slice "a" and vertical slice "b" of the beam trace pattern 120 ms after the beginning of the movement (0 ms).

shorter than the characteristic exponential relaxation time of the steady state of the QDs colloid. Here we recall that the pattern of the beam trace profile is a pattern of wave aberrations of the wave surface of the light-induced refractive index volume [17, 18]. The photoinduced refractive index of a colloid of QDs results from the accumulation of the concentration of QDs with a light-induced metastable exciton [16]. Consequently, the transformation of the pattern of the beam trace profile is the result of the transformation of the distribution of the concentration of QDs with a metastable exciton in the illuminated volume of the QDs suspension. **Figure 4** convincingly shows that a substantial concentration of QDs with a metastable exciton, providing phase addition to the wave front of the input beam, for example, at 14π disappears without a trace for a time shorter than the characteristic relaxation time of the steady-state stationary concentration of QDs.

In principle, this behavior of the QDs concentration is expected. Micro-shaking is a source of forces that can cause flows in a liquid, which mix the concentration of QDs. But, the fact is that micro-shock causes forces with an arbitrary direction. It is obvious that such forces should cause arbitrary concentration flows in a liquid, which should cause an arbitrary geometric displacement of the optical beam, its axis, in the first place. The experiment shows that arbitrary QDs concentration fluxes with a metastable exciton really arise, but all these fluxes "spin" around the axis of the input optical beam. The axis of the input beam has "unshakable" directions and retains its direction for all mechanical perturbations of the cell with QDs colloid. This means only one thing: there are no real flows of QDs concentration in the liquid, and what we see is the result of teleportation of the quantum states of a metastable exciton. Quantum teleportation "transfers" only quantum states from one quantum object to another quantum object. The trajectory of the transfer, of course, is absent. We have implemented a unique situation where mechanical classical forces are small enough to cause a real disturbance of the fluid, but these forces easily cause quantum teleportation, which does not have a trajectory of movement in classical space. The lack of a trajectory of movement clearly means that there is no actual movement of objects in space. Obviously, there is no movement; therefore, there are no forces that prevent this movement. This means that what we see is the result of the direct action of the forces not "burdened" by the opposition of any other forces.

The fundamental and practical significance, as well as novelty, of these results cannot be overestimated. The fundamental significance and novelty lies in the fact that the resource of entangled quantum states creates a macroscopic wave function regardless of temperature. Quantum teleportation transports quantum states of neutral particles, for example, quantum dots with a metastable exciton, without a specific trajectory of motion in classical space. Since there is no movement trajectory, then there is no movement itself. Movement is not, means that there are no forces that impede movement. There are no such force, which means that there is no internal friction. There is no internal friction in a fluid, for example, in a colloid of quantum dots, and there is a real displacement of a quantum dot, since a quantum state with a metastable exciton is another stable quantum state of quantum dots in classical space, and therefore it is another quantum object. Moving quantum objects in a liquid without internal friction is the basis for the implementation of a superfluid quantum liquid, regardless of temperature. Superconductivity can be realized regardless of the temperature on the same quantum entanglement resource, but for this it is necessary to confuse the quantum states of charged qubits.

Practical significance and novelty lies in the fact that quantum teleportation allows you to register super-weak forces. Obviously, a super-weak force can impart to a super-small mass a sufficiently large acceleration, which is easy to register, especially in the absence of internal friction. On this basis, the possibility of developing super sensitive sensors, for example, for registration of gravitational waves, but in the size of an ordinary laboratory table opens.

To conclude this section, we formulate the physics of the quantum teleportation process of entangled quantum states. The obvious condition of quantum teleportation is that entangled quantum states must occupy a macroscopic volume. It is the volume in which the geometric displacement of quantum states takes place. In this work, this volume determines the geometry of the input optical beam, as well as, for example, in [20]. This optical beam light induces a second stable quantum state (QD with a metastable exciton) from the first state (QD in the ground quantum state), in other words, the optical beam generates classical two-level qubits, which at a sufficiently high concentration self-organize into a quantum state of quantum superposition with 2^N entangled quantum states. Decoherence takes place under the influence of both internal and external forces. It is under the action of these forces that the "disentangling" of 2^N quantum states into one of the stable states $|0\rangle$ or $|1\rangle$ of each individual qubit from N classical qubits takes place. The concentration distribution of these particular qubits is easily measured, since they are already in the classical space. The specific geometrical place where the quantum states $|0\rangle$ or $|1\rangle$ fall into is determined by internal forces (concentration compression as QDs accumulate with a metastable exciton) or external forces (whistle of the beam trace profile pattern). An analogue of the physics of such teleportation is the precipitation of raindrops (quantum states) from a macroscopic rain cloud (quantum superposition) under the action of internal forces (for example, the turbulent distribution of condensation centers) or external forces (for example, turbulent flows or wind gusts).

3. Quantum gravity as macroscopic force

Quantum gravity is a well-established term in the framework of the creation of the unified field theory, and this term means a quantum description of gravitational interaction. Obviously, the process of describing the gravitational interaction is not related to the emergence of gravitational force, as a fundamental force that plays a key role in nature. I propose to return quantum gravity to its original meaning as the primary source of interaction forces in nature. Quantum mechanics and general relativity are two fundamental theories that underlie the theory of quantum gravity. But, these theories are based on supposedly different a conceptual principle, which does not allow creating a unified field theory based on the theory of quantum gravity. Direct experiments in the field of quantum gravity are inaccessible to modern technologies due to the weakness of gravitational interactions. This is only a short list of difficulties that arise when trying to understand what quantum gravity is. I propose to combine the supposedly different conceptual principles of quantum mechanics and the general theory of relativity not to create a theory of Kant's gravity, but for the experimental realization of quantum gravity as a macroscopic force.

Obviously, any quantum object has mass. Then, the gravitational interaction between these objects, as bodies having a certain mass, is called quantum gravity by analogy with the classical concept of gravity. The mass of quantum objects is very small, and then it is obvious that the force of such quantum gravity, due to mass, can play a significant role and be detected at very small distances. It is believed that this distance determines the absolute unit of Planck's length, which is 10^{-33} cm. Penetration into the scale of units of length and Planck's time requires the creation of a density of 10^{99} cm^{-3} objects. For this you need to build a collider size, probably from the Milky Way. These are supposedly obvious direct experiments, the technology of which cannot be realized at the present time.

I propose another technology for creating quantum gravity as a macroscopic force precisely on the basis of the conceptual compatibility of quantum mechanics with the general theory of relativity. For this, I propose to assume that quantum gravity, as a force, is the result of the space-time curvature of the field from the point of view of the general theory of relativity. And from the point of view of quantum mechanics, the source of quantum gravity should bend the space-time field at the quantum level. The moving mass creates a curvature of the space-time field in classical space; therefore it is the source of classical gravity. Then, by analogy, quantum gravity should arise as a result of a quantum process that bends the space-time field at the quantum level. Such a process exists and is generally known. This process is the transition of any quantum object from one quantum state to another quantum state, since the wave function of any quantum state transforms itself in space and time, and therefore bends space-time, with any change of quantum states. This is a well-known and generally accepted experimental fact. It is obvious that the curvature of the space-time field and, therefore, quantum gravity, as a force, will increase with an increase in the number of such quantum transitions. I propose to consider a quantum state called quantum superposition as a kind of quantum space that contains 2^N entangled quantum states, where N is the number of quantum objects that participate in quantum superposition. The reason for this proposal is simple. Only quantum superposition provides an exponential increase in the number of quantum states and, thus, entangles all quantum states of quantum superposition and provides an exponential increase in the number of transitions of quantum objects from one state to another as a result of decoherence of quantum superposition. Indeed, quantum superposition, for example, from $N = 1000$ quantum objects contains $2^{1000} = 10^{301}$ entangled quantum states, which become $N = 10^3$ stable quantum states in the classical space during the collapse (decoherence) of quantum superposition. Therefore, decoherence of quantum superposition of 1000 objects provides 10^{298} mutual transitions of quantum states, which is many orders of magnitude greater than the density of quantum states necessary for experimental work on the scale of absolute Planck units.

3.1 The results of the experiment and discussion

The experimental results of part 2 of this article substantiate the teleportation of quantum dots with a metastable exciton under the action of external classical forces. This teleportation is the result of quantum teleportation of the “metastable exciton” quantum state. This result looks like a fantasy, but this result is a physical reality, since the qubit is a quantum object in two stable basic states. This means that a qubit in the state (QD in the ground state) and a qubit in the state (QD with a metastable exciton) are different quantum objects in the classical space. **Figure 1b** shows the transformation of the pattern of the beam trace profile in the process of achieving a steady state. A nonlinear optical response is formed as a result of a photoinduced change in the refractive index. QDs with metastable excitons are the direct source of this photoinduced refractive index. Therefore, the stationary state of the nonlinear response is established when the concentration of quantum dots with a metastable exciton is established in the stationary state. And this is due to the accumulation of quantum dots with a metastable exciton, as a state with a long relaxation time. Therefore, the unique flattening of the upper half of the beam profile pattern should be associated with the accumulation of QDs in the state. The experimental results of **Figure 5** confirm this statement and show how the beam trace profile “comes” to its stationary state when the colloid was in the position $z = -25.5$ cm $= -49z_0$. The input optical beam had a radius $w = 1374$ μm, which causes sufficiently long diffusion times for the accumulation of quantum dots with a metastable exciton. This makes it possible to record all stages of the transformation of the beam trace profile in sufficient detail, since the registration took place with a digital camera with an interval between frames of 40 ms. Another “highlight” of the experiment in this position along the Z axis is that the intensity of the input optical beam was ~1 W cm^{-2}.

The fact is that the authors of almost all works consider that if the optical medium absorbs optical radiation, then the nonlinear optical response is thermal nonlinearity. Thermal nonlinearity is a consequence of a decrease in the density of the optical medium as a result of its heating. The non-linear thermal lens is, as a rule, negative and it defocuses the optical beam. The defocusing of the optical beam manifests itself as an increase in the size of the beam trace profile on a remote screen.

Figure 5 shows, with all the evidence, that the size of the beam trace profile coincides with the size of the input beam trace profile during the entire time of establishment of the steady state. This means that there is no thermal nonlinear lens, and a unique transformation of the output beam profile pattern is present. Therefore, the flattening of the beam trace pattern is a result of the action of forces that increase with the accumulation of QDs with a metastable exciton.

The obvious direction of action of these forces is shown in **Figure 6**, which shows the transformation of the pattern of the beam trace profile in the position of a cell

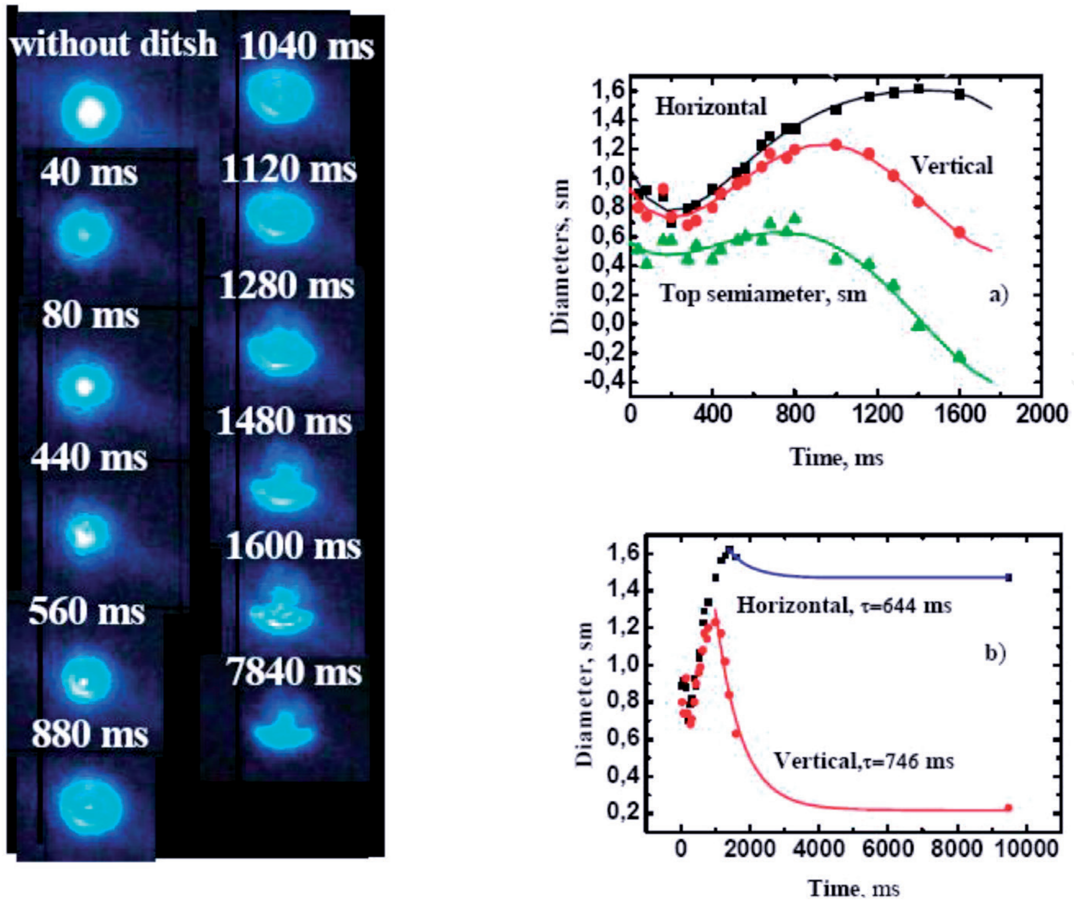


Figure 5.
The photographs represent the profile of the beam trace in the process of establishing a steady state. The numbers have time after the start of the lighting. (a) Represents the beginning of the development of transformation; (b) shows the relaxation of the beam trace size to the stationary mode.

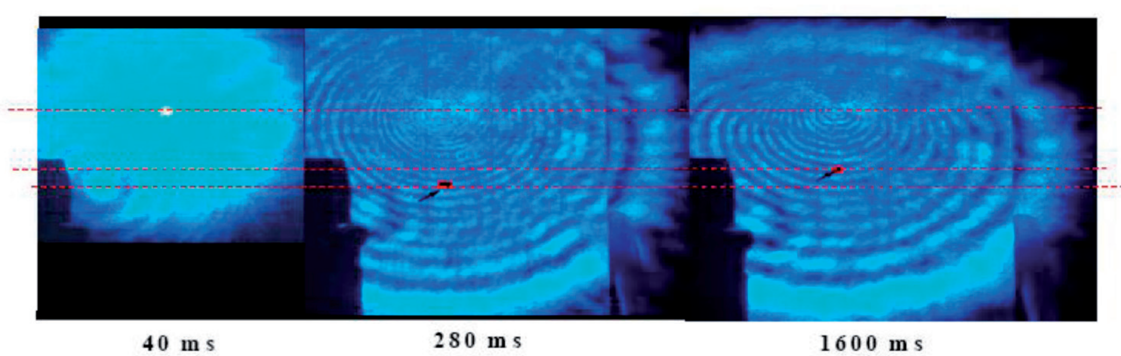


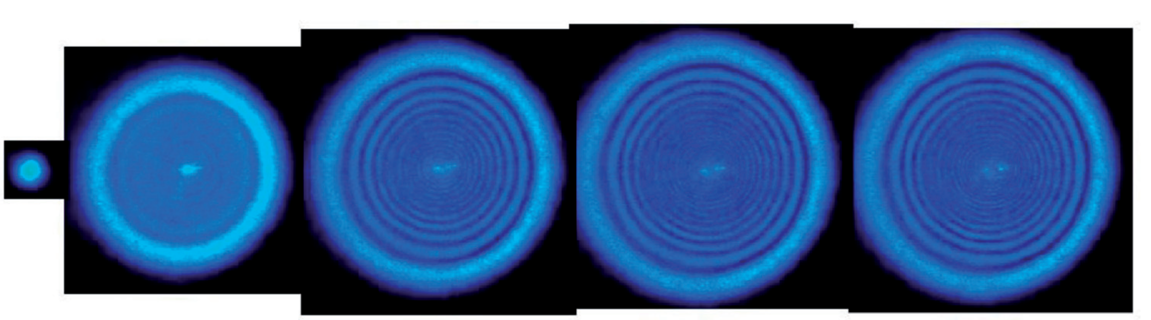
Figure 6.
Transformation of the pattern of the beam traces profile when the cell was in the waist of the input beam. The numbers have time after the start of the lighting.

with a colloid near the waist of the input optical beam. The input beam has a maximum intensity, and it illuminates the minimum volume of the nonlinear medium in this position. Therefore, the curvature of the wave front of the light-induced lens increases in comparison with the curvature at positions far from the waist of the input beam. The optical power of this lens also increases. The size and number of rings of the beam trace profile pattern increases, and the time to steady state is reduced. The files videos 1–3.gif demonstrates the transformation of the beam trace profile for this position of a colloid cell in real time. Collapse (self-focusing) of the optical beam takes place at the very beginning of illumination of a nonlinear medium. A typical Townes profile [21] is formed in the first 40 ms after the start of illumination. A dozen rings are formed already to 120 ms after the start of illumination. The increase in the number of rings and the simultaneous "lowering" of the whole pattern of the beam trace profile downward is observed in the time interval 160–600 ms after the start of illumination. Subsequently, the upper half of the beam trace continues to descend, forming only three contrasting rings that do not "go" beyond the horizon, as at $z = -48z_0$ and the rings of the pattern of the lower half of the beam trace profile "tighten" to their center, which is located on the axis of the input optical beam. As an example, the ninth from the outer ring, marked by a dot in **Figure 6** (280 ms), is shifted to the place of the 11th ring (1600 ms) during the time interval of 280–1600 ms after the start of illumination. Thus, we see that the upper half of the beam trace profile descends almost to the axis of the input beam, while the lower half of the interference pattern descends first and then, after some time, "tightens" up to the axis of the input beam. This is one of the key results of the experiment, and it indicates that the light-induced force is directed to the center of the input optical beam, i.e., it is directed to the axis of the optical beam.

The photos in **Figure 7** demonstrate the pattern of the beam trace profile when the colloid shines through in the vertical "bottom-up" direction. It can be seen that the beam trace profile remains axisymmetric all the time. Transformation of different parts of the beam trace profile is absent.

Obviously, the horizontal scanning of the colloid differs from the vertical in that the gravitational force of the Earth is directed perpendicular to the beam axis, whereas with vertical scanning the gravity force is parallel to the beam axis. In other words, we are in a situation where two mechanical forces have different directions. One force is terrestrial gravity, and it is directed vertically downwards, and the other force is light-induced force and it is directed to the axis of the optical beam. Then, the resultant force is the sum of two forces in the upper half of the beam trace profile, and there is the difference of these forces in the lower half of the beam trace profile. As a result, the upper half of the beam profile is compressed almost completely, and the lower half of the profile is compressed slightly.

Section 2.2 of this paper justifies the property of QDs to form quantum superposition with 2^N entangled quantum states under CW-illumination by an optical beam. The continuous repeating cycle "self-assembling quantum superposition—decoherence of quantum superposition—and self-assembling again" provides an unimaginably large number of quantum transitions "N states—in 2^N quantum states—decoherence in N states." These quantum transitions provide, in turn, an unimaginable number of curvatures of the space-time field with quantum objects, which are QDs. And this is quantum gravity in the literal sense: quantum gravity is mechanical force. Judging by the results, for example, in **Figure 5**, the light-induced quantum gravity force somewhat exceeds the force of the earth's gravity, since the



40 ms 120 ms 320 ms 800 ms 1960 ms

Figure 7.
Profiles of the beam trace profile reflect the transformation of the progeny when the nonlinear medium shines through in the vertical direction: from bottom to top.

sum of these forces flattens the pattern of the upper half of the beam almost completely, and the difference of these forces slightly affects the pattern of the lower half of the beam trace profile.

The practical significance of such a force of quantum gravity solves the long-term problem of thermonuclear fusion of nuclei. The modern concept of nuclear synthesis suggests that plasma temperatures of 10^8–10^9 K will provide automatic synthesis of nuclei with a positive energy output. This concept is based on experimental results that are obtained repeatedly on particle accelerators. The real synthesis of nuclei in the *H*-bomb takes place, ostensibly, both because of the high temperature and because of the extremely high pressure, which arises as a result of the material being compressed by *X*-rays. *X*-ray radiation is an external force that can, in principle, compress the material, but this force is external and due to various kinds of fluctuations in the material, uniform compression is impossible, in principle. Quantum gravity is an internal force and, precisely, internal forces are capable of compressing the material evenly. Therefore, the real role of *X*-rays in the *H*-bomb is to create a quantum superposition of such a large *N*, that quantum gravity in the material of the *H*-bomb can be comparable to gravity in the center of the sun. The result is—lit a piece of the sun in terrestrial conditions.

4. Conclusion

In conclusion, the concept of quantum gravity was proposed for the first time as a force that arises as a result of the space-time field curvature at the quantum level when a quantum object passes from one state to another quantum state. The concept of real quantum space was first proposed as a quantum state of a multi-particle quantum superposition of *N* quantum objects, which contains 2^N entangled quantum states. The decoherence of quantum superposition takes these 2^N entangled quantum states into one of two stable quantum states for each of the *N* quantum objects. This process provides an exponential increase in the number of quantum transitions, and, thus, can provide conditions in which the force of quantum gravity reaches a macroscopic value.

Multi-level semiconductor quantum dots were first proposed as light-induced *q*-bits. The second stable quantum state of these *q*-bits is effectively separated from other excited quantum states of quantum dots due to the large relaxation time, which are six orders of magnitude longer than the relaxation time of other excited states of quantum dots. Light-induced charges carriers can be captured by surface-trapped QDs states and, thus, form an exciton with a long diffusion relaxation time. Such a quantum state of QDs is called QDs with a metastable exciton. Such QDs have a large individual additive to their refractive index due to the large spatial separation of charge carriers. The registration of the space-time redistribution of individual QDs was performed for the first time as the registration of the wave aberration pattern of the light-induced wavefront of the QDs suspension. This picture was the actual distribution of the refractive index in the volume of the QDs suspension illuminated by a laser beam. The experiments were performed under continuous illumination of the QDs suspension with a laser beam. This means that the quantum space (quantum superposition) functioned continuously according to the pattern of communication with the classical space: "creating a quantum superposition—decoherence of a quantum superposition—creating a quantum superposition again—decoherence of a quantum superposition again—and so on. Decoherence is the transition of entangled quantum states of quantum superposition into one of the stable quantum states in classical space. These two stable quantum states had different amounts of addition to their refractive index. It was these states that changed the light-induced wavefront in a QDs suspension, whose wave aberrations were recorded as a beam trace profile on a remote screen.

The experimental results show that two light-induced fundamental processes manifest themselves in the QDs suspension, which were revealed due to a significant change in the lighting conditions of the QDs suspension (Z-scan range from $z = -49z_0$ to $z = +60z_0$) and time measurements, as the QDs suspension comes in its stationary state. The nonlinear optical response of the QDs suspension, as a nonlinear optical material, is the first process, the maximum value of which is achieved at $z = \sim z_0$. The emergence of a certain light-induced force, which flattens the upper half of the beam trace profile during horizontal scanning QDs suspension, is the second fundamental process. Such flattening of the beam trace profile manifests itself to the greatest extent under conditions when there is no nonlinear-optical response (very large detuning of Δz from the beam waist). The flattening of the beam trace profile is absent when the QDs scan suspension is vertically translucent, which suggests that the flattening of the beam trace profile has a gravitational basis. An analysis of all the details of the experiment allows us to conclude that the macroscopic force of quantum gravity was first implemented in the simplest laboratory conditions.

The result is fundamentally new; we can say there is a revolutionary one, not only for quantum physics, but also for the entire world view, from cosmology to the functioning of all life. Naturally, this result does not coincide with the modern concept of the development of quantum physics, especially if we take into account the complete absence of the mathematical apparatus for quantum space, therefore, the result is fundamentally new. The experimental results shown in this article, for example, quantum teleportation based on the formation of a macroscopic wave function, justify fantastic possibilities to realize the Bose-Einstein condensate regardless of temperature.

Author details

Anatolii Isaev
P.N. Lebedev Physical Institute (FIAN), Moscow, Russia

*Address all correspondence to: anaisaev@yandex.ru

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