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Research Article

Two Signs of Superfluid Liquid in a Suspension of CdSe/ZnS Quantum Dots at Room Temperature

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The paper presents experimental results of the interaction of a focused optical beam with a suspension of CdSe/ZnS quantum dots in toluene. Two autographs characteristic only of the behavior of a superfluid quantum liquid were experimentally observed. The first was the fountain effect from the region of local heating of the suspension with an optical beam; the second was the complete "creeping out" of the QDs suspension in the form of a thin film along the walls of the cuvette in which the suspension was located. The results of the work suggest that superfluid quantum liquid may arise at room temperature as a result of the functioning of many-particle quantum superposition. Bose-Einstein condensation of entangled quantum states is proposed as a physical mechanism for producing a superfluid liquid, regardless of temperature.

1. Introduction

Bose-Einstein condensation is a generally recognized physical mechanism for the formation of a superfluid quantum liquid in classical space. The physics of the process is quite simple. The speed of particles and the average distance between them are quantities that describe the interaction of particles in classical physics. The de Broglie heat wave λ_{dB} determines the interaction of particles in the quantum case at low temperature. The value λ_{dB} becomes comparable to the mean distance d between the particles when the temperature is lowered and the wave packets particles begin to overlap. The wave packets of a part of such particles overlap and are already described by a macroscopic wave function, which corresponds to the so-called nucleation of a superfluid liquid. Finally, the complete overlap of the wave packets of all particles takes place at a temperature $T \sim 0$ K. Quantum particles are completely condensed into a superfluid quantum liquid. The superfluidity of He^4 was discovered in 1938 [1, 2]. A typical autograph of a superfluid fluid is the flow of fluid from a heated region (thermomechanical effect), which is a consequence of the movement of a quantum fluid due to the temperature difference, and not the pressure difference. Another effect is the "creeping out" of this liquid from the vessel along its walls due to the absence of internal friction, which is absolute wetting.

The de Broglie heat wave λ_{dB} depends not only on temperature, but also on the mass of quantum objects. Bose-Einstein condensation takes place for light objects at a higher temperature than for "heavy" ones. Superfluid condensate of liquid helium was obtained at $T \sim 2$K, and a condensate of rubidium atoms with a mass of $\sim 10^5\ m_e$ was obtained already at $T \sim 1\ \mu$K [3]. A large amount of research was carried out with condensates, which consist of interacting photons, such as microresonators exciton polaritons [4–8]. Polaritons have a very small mass $m \sim 10^{-5}\ m_e$, a sufficiently large coherence length $\lambda_T \sim$ 1-2 μm, and the average distance between polaritons $d =$ 0.1-0.2 μm, which is the basis for the implementation of many-particle coherent quantum effects in classical space. Quantum effects were implemented in microresonators with quantum wells of semiconductors of groups III-V or II-VI embedded in them. Many quantum effects were obtained already at temperatures below 20 K. At temperatures above 20 K, excitons are autoionized. This is a consequence of the low binding energy characteristic of Wannier-Mott excitons.

Superfluid polariton liquid at room temperature was obtained in [9]. Superfluidity manifested itself as the disappearance of scattering in the interaction of fluid flow with a mechanical obstacle in this flow. Superfluid condensate was obtained by replacing inorganic semiconductors with organic compounds that maintained stable Frenkel exciton polaritons at room temperature. Obviously, working with a superfluid liquid at room temperature is of particular interest. Such interest is due to not only a substantial simplification of the experimental techniques of basic research, as such, but also, mainly, the possible creation of real instruments and devices based on liquids without internal viscosity.

Bose-Einstein condensation is a quantum-mechanical process in classical space, in which there are temperature, mass, momentum, and coordinate. I propose another concept of the possible creation of a quantum superfluid liquid in which classical concepts such as temperature, mass, and others are absent and, therefore, they do not affect quantum processes, in principle. We are talking about the quantum state of a multiparticle quantum superposition, which contains 2^N entangled quantum states, where N is the number of two-level quantum objects. A macroscopic array of entangled quantum states can perform the same function as the macroscopic wave function of Bose-Einstein condensate in classical space. This is the essence of the concept of implementing quantum effects regardless of the ambient temperature.

The purpose of this work is to present the results of experimental studies of the behavior of suspension of CdSe/ZnS quantum dots under conditions of multiparticle light-induced quantum superposition and, thus, to show the possibility of obtaining a quantum liquid at room temperature.

2. Quantum Superposition as a Quantum Space

Quantum superposition is a quantum state, which, like other quantum states, has its wave function. This is a key property of quantum superposition. Quantum superposition is a linear combination of quantum states of all quantum objects of generators or members of it. A quantum superposition can be formed by one quantum object, if this object has two stable quantum states. A simple example is a photon in two polarization states "*o*" and "*e*". A multiparticle quantum superposition is a linear combination of the quantum states of all quantum objects that form it or participate in its creation. The main requirement for these quantum objects is that these objects have two stable quantum states. In other words, this quantum object should be a two-level quantum system of ground state $|0\rangle$ and excited state $|1\rangle$ in the Cat notation of vectors. Then the quantum state

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

where α and β are complex numbers, the sum of squares of which $|\alpha|^2 + |\beta|^2 = 1$, is quantum superposition. In essence, $|\alpha|^2$ and $|\beta|^2$ are probabilities of obtaining the state $|0\rangle$ or $|1\rangle$ of a quantum object after it leaves the state of quantum superposition. Leaving the state of quantum superposition, as a result the collapse of the wave function was called decoherence quantum superposition. The result of decoherence is the appearance in the classical space of the original object in one of the states $|0\rangle$ or $|1\rangle$ with probabilities $|\alpha|^2$ or $|\beta|^2$, respectively. The quantum state of a quantum superposition of two quantum objects is written as

$$|\Psi\rangle = \alpha_{00} |00\rangle + \alpha_{01} |01\rangle + \alpha_{10} |10\rangle + \alpha_{11} |11\rangle , \tag{2}$$

where

$$\left|\alpha_{00}\right|^2 + \left|\alpha_{01}\right|^2 + \left|\alpha_{10}\right|^2 + \left|\alpha_{11}\right|^2 = 1 \tag{3}$$

We see that two two-level quantum objects form a quantum state of quantum superposition, which contains four interconnected quantum states. And the quantum state of quantum superposition of N quantum objects already contains 2^N interconnected quantum states. Such interconnected quantum states are called entangled quantum states. Entanglement can be felt as the interaction of all quantum objects of quantum superposition with each quantum object and vice versa, the interaction of each object with all other objects. The resource of the exponential growth of the number of quantum states of quantum superposition with a linear increase in the number of quantum objects is a fundamental property of a linear combination and, therefore, is not associated with energy expenditures on the formation of entangled quantum states. In other words, the law of conservation of energy functions in quantum superposition not in the same way as classical space. This is a key fact that lies in the substantiation of the statement or proposal that quantum superposition is a real quantum space with its own laws, which are fundamentally different from the laws of classical physics.

The Schrödinger's Cat paradox highlights the key properties of quantum superposition and substantiates the way to work with quantum superposition. Everything that takes place in a quantum space (quantum superposition, a quantum box, by definition of the fathers of the founders of quantum mechanics) is inaccessible to us in classical space. This result occurs when quantum objects emerge from superposition as a result of decoherence (they opened the quantum box where the cat was). Decoherence translates a 2^N array of entangled quantum states into an N array of quantum states in a classical space. Each object from the N array acquires one of its stable quantum states $|0\rangle$ or $|1\rangle$, whose characteristics can be measured, since these states are states of classical space. Therefore, the manufacture of two stable states of a quantum object is the first key task of organizing quantum space and experimental work in it. Such objects in two stable quantum states are called q-bits in the framework of the program "quantum computer". As part of this program, artificial q-bits were developed and created at the edge of the capabilities of modern experimental techniques. An example is charged q-bits based on superconductivity islands with a different number of Kupper pairs. I propose to use them as qubit natural quantum objects, which are multilevel quantum systems. Multilevel systems can also be used if they have two states that can be effectively separated from the rest (for example, the ground state and the first excited state of a nonlinear oscillator).

CdSe/ZnS semiconductor quantum dots (QDs) were used as q-bits in this work. A quantum dot is a multilevel quantum system; therefore, the ground unexcited quantum state of this QD was used as the first stable quantum state that participated in the formation of quantum superposition. The second stable q-bit quantum state was formed from the first steady state, as a result of light-induced separation of charge carriers inside QDs, followed by the capture of one of these charge carriers by surface trapping states. The effective separation of this quantum state from all other excited quantum states of QDs was realized on the basis of a significant difference in the relaxation time of this quantum state compared to other quantum states. The characteristic relaxation time of such a quantum state lies in the millisecond range [10–13]. This time exceeds the characteristic time of exciton luminescence, which is the main channel of relaxation of separated charge carriers, by 6 orders of magnitude, which allows us to consider this quantum state of QDs as the second stable quantum state of q-bits. Such a QDs is called a QDs with a metastable exciton [14].

The results of quantum processes in quantum space are of fundamental interest for quantum physics, but these results can be measured only in classical space. Therefore, the ability to perform such measurements in the form of dependencies between classical quantities is a key problem of the interaction of quantum processes with classical processes. Therefore, registration or measurement of the results of the presence of quantum objects in quantum space was another experimental key task. The fact is that in quantum space or in a quantum "box" by definition of the "founding fathers" of quantum mechanics, it is impossible to measure anything, since any "intervention" in the quantum space, which is measurement, leads to quantum space collapse. The state of a quantum object can be measured with great accuracy only in the classical space in which we exist and function, and in which quantum objects fall from quantum superposition as a result of the decoherence process. The quantum space decoherence transforms the quantum state of each q-bit from an array of entangled states into one of the stable states of this q-bit in classical space, where the characteristics of these states can be measured.

For this, I propose to use the optical nonlinearity of QDs with a metastable exciton or qubit in the second stable quantum state $|1\rangle$. The nonlinear optical response of the QDs suspension occurs for two reasons. The first reason is heating, since the suspension is an absorbing medium. Heating reduces the density of molecules in the heated region, and, consequently, the refractive index. The second reason has an electronic mechanism for the formation of a nonlinear-optical response. The absorption of a quantum of light with energy greater than band gap separates the charge carriers and forms excitons inside the QD. The recombination of excitons is the source of exciton luminescence; the quantum yield can be up to 80% [15]. This means that the bulk of the absorbed light energy is spent on electronic, rather than on thermal processes. A metastable exciton arises as a result of the capture of a photo-induced electron by a surface QD trap. This means that the separation of charge carriers takes place on the size of the QD, which is several nm. Therefore, the polarizability of such a QD in the electric field of a light wave is many times greater than the Kerr polarizability of transparent dielectric molecules [16, 17]. This means that nonlinear-optical properties of individual QD, which have an additive to the refractive index due to metastable excitons, come to the fore. The magnitude of the additive to the light-induced refractive index of an individual QD with a metastable exciton significantly exceeds the Kerr additive to the individual refractive index of the dielectric molecule only by increasing the individual dipole moment. A large addition to the refractive index of an individual QD makes it possible to register the space-time redistribution of individual QDs with a metastable exciton by converting the phase relations into the intensity distribution.

The registration of the wavefront aberration pattern [18–21] of the light-induced refractive index was used to solve this problem. A simple measurement scheme has been implemented. The laser beam created q-bits, which were organized into many-particle quantum superposition as a result of self-assembly. The interaction of quantum states in quantum superposition took place at the expense of forces, both in the quantum superposition itself and in the environment. Decoherence in quantum superposition occurred as a result of the action of these forces. Decoherence translates all quantum states of quantum superposition into stable quantum states of each q-bit in classical space. Each q-bit with a metastable exciton has in the classical space a sufficiently large addition to its refractive index. This additive introduces an additional phase shift into the wavefront of the laser beam, which illuminates the colloid QDs. The visualization of this wavefront, as a pattern of wave aberrations, took place on a screen remote from the cell with a colloid. The laser beam illuminated the colloid QDs continuously, and it played the role of a driving force that created the second stable quantum state of QDs from the first steady state, like q-bit. Therefore, when decoherence destroyed the quantum superposition and transferred all the quantum states of this superposition to one of two quantum states of q-bits in classical space, then the laser beam created the q-bits again, which formed the quantum superposition (quantum space) again. Therefore, the process of interaction of the classical space with the quantum space lasted continuously until the laser beam, as a driving force, illuminated the colloid QDs.

3. Experiment

The scheme of the experiment is shown in Figure 1. The colloid of CdSe/ZnS quantum dots (size 3.8 nm) in toluene was used as the optical medium in the classical space [10]. The CdSe/ZnS QDs colloid cell was 5 mm thick and was illuminated by a focused cw beam—a single-mode laser with λ=473 nm and a power of 30 mW. The profile of the laser beam trace, which passed through the colloid, was observed on a screen removed from the cell and photographed with a digital camera with a frame rate of 25 Hz. The parameters of the Gaussian laser beam input into the colloidal medium were angle of beam convergence $\theta=w/L=5.45\,10^{-3}$; $w_0=\lambda/\pi\theta=$ 28 μm in the waist of the beam; $I_0=2P_l/\pi w^2$, $z_0=\pi w_0^2/\lambda=$ 5.2 mm. The results of the experiments were obtained at different

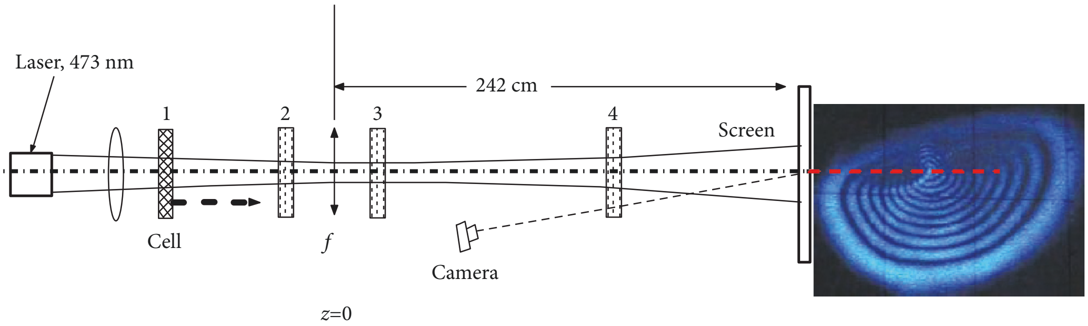

Figure 1: The scheme of the experiment and the profile of the laser beam trace on the screen.

fixed points on the z axis (1–4) in the range of $z = (0 \div \pm 25.5)$ cm or $z = (0 \div \pm 49)\, z_0$. This made it possible to conduct studies in a large range of changes, both in intensity (due to a change in diameter) and curvature of the wave front of the input beam. The absorption of a colloid with QDs was linear and was 1.48 cm^{-1} at a wavelength of 473 nm. The absorption cross section of these QDs at this wavelength $\sigma = 4.2\ 10^{-15}$ cm^2 [15], which makes it possible to estimate the density of QDs in a colloid as $N = 3.5\, 10^{14}\ \mathrm{cm}^{-3}$. The laser photon energy exceeded the band gap of the quantum dot, so the laser beam photo-induced charge carrier separation, which, according to [17], gave a negative addition to the classical refractive index of an individual QD with a metastable exciton. The many-body array of such QDs introduced a negative phase addition to the wave front of the input optical beam in accordance with the space-time distribution of the QDs concentration with a metastable exciton. The space-time distribution of photo-induced separated charges should repeat the space-time distribution of the intensity of the input Gaussian beam, if the absorption is linear, which is realized in our experiments.

The intensity distribution on the screen or the beam trace profile is formed by a light-induced lens [19], which occurs as a result of the space-time redistribution of the concentration of QDs with a metastable exciton as a result of colloid illumination. Therefore, the profile of the beam trace on the screen is usually considered as a picture of the wave aberrations of the wave surface of this light-induced lens [20, 21]. Wave aberrations of the Gaussian wave surface are well known and their pattern contains a wide and bright outer ring and a set of inner rings with diminishing brightness and distances between the rings towards the center of the pattern [18]. A typical, but already somewhat distorted, picture of the wave aberrations of the Gaussian wave front is shown in Figure 2 (frame 320 ms). The wave surface of the input optical beam is Gaussian and constant in time for a continuous single-mode laser beam. Therefore, any change in the pattern of the beam trace profile on the screen is the result of the action of certain forces on the space-time distribution of the concentration of quantum dots with a metastable exciton.

4. Results of the Experiment

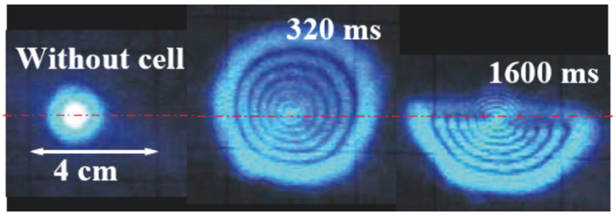

Figure 2: Typical transformation of the beam trace profile with the accumulation of QDs with a metastable exciton and the achievement of a stationary nonlinear-optical response.

The transformation of the shape and pattern of the beam trace profile takes place immediately after the start of illumination of the QDs suspension, which reach their steady state after 1-2 seconds. Figure 2 shows an example of such a transformation of the beam trace profile pattern. Quantum dots with a metastable exciton have a long relaxation time (~ hundreds of microseconds), so their concentration accumulates in time after the start of illumination. Therefore, the transformation of the pattern in time can be associated with the forces that manifest themselves as the QDs accumulating with the metastable exciton. Figure 3 shows how the transformation of the pattern of the beam trace profile changes in different positions of the cell with QDs along the z axis, when the input beam has different diameters and curvature. The diameter of the input beam determines the magnitude of its intensity, and the curvature of the wave front determines the sign of the nonlinear-optical response. A converging optical beam has a negative wavefront curvature, so it experiences self-focusing in a negative nonlinear medium, while the diverging beams defocus. Figure 3 illustrates this behavior; we see self-focusing for negative positions along the z axis and defocusing for positive values of z. The input optical beam was continuous and had a power of 30 mW. The linear absorption of radiation provides the same amount of accumulated QDs with a metastable exciton. But if the diameter of the input beam decreases due to the approach of the cuvette with QDs to the beam waist, then the concentration gradient of these QDs increases; as a result, the steepness of the wave surface of the light-induced refractive index also increases. The optical force of the light-induced lens increases, which leads to an increase in the diameter of the beam trace profile (see Figures 2 and 3).

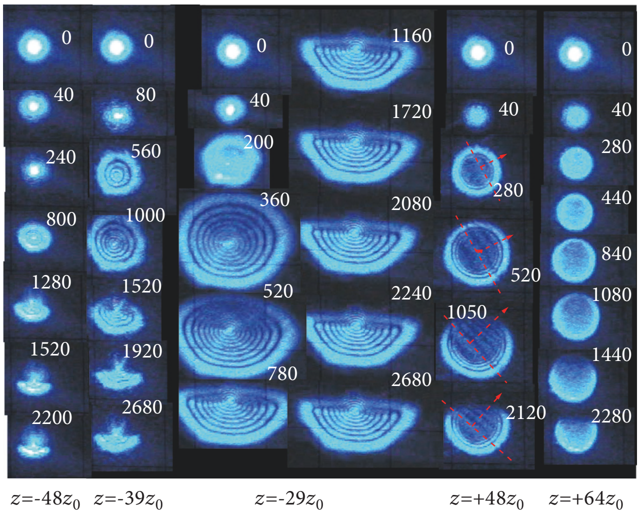

Figure 3: The establishment of the beam trace profile for different positions of the nonlinear medium. The numbers have a time (ms) after the start of the lighting.

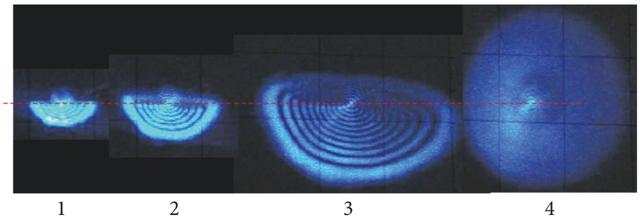

Figure 4: The trace profile of a converging optical beam at different positions of the nonlinear medium along the z axis.

We see for the converging input beam the profile of the beam trace in the steady state has a light structure of the "fountain" type, which emanates from the center of the beam trace profile that coincides with the axis of the input beam. "Fountain" has the shape of a cone and a uniform gradation of optical density, which corresponds to an optical path difference of ~ 7λ. This article discusses experimental results that are specific to this "fountain" type of light structure. The light structure of the fountain type becomes visible in the beam trace profile as the upper half of the beam trace profile flattens and wraps over the horizon. The process of manifestation of the "fountain" is shown by the video file Video 1 and Video 2 (see the appendix to the article). We can see that the dimensions of the "fountain" change little in the time interval when the fountain begins to be visible. The fountain origin process is masked by a high intensity nonlinear optical response.

Figure 3 presents selected photographs of the beam trace profile for different cell positions along the z axis. These photographs reflect the characteristic details of the temporal transformation of the beam trace profile pattern after the start of illumination. It can be seen that, immediately after the start of illumination, the self-channeling waveguide mode of the optical beam propagation takes place. For the position of the cuvette z = -25.5 cm = -49z_0, this period of time lasts 0-300 ms. For other positions of the cuvette on the z axis, this time period is reduced. Then the optical beam propagates in the transverse self-phase modulation mode. The beam trace profile is, in this mode, a set of axisymmetric round interference rings with a characteristic distribution of their intensity (wide and bright outer ring). The key result of the experiment takes place in a time interval of ~ 1 second and it manifests itself in the fact that the upper half of the beam trace profile is flattened and "wrapped" beyond the horizon, exposing a certain light structure in the form of a fountain. For the positions of the cuvette z <-30z_0 in the fountain, its own internal interference structure arises. The fountain is absent for positive values of z; instead of a fountain a dark spot develops, which seems to be drawn inside the pattern of the beam trace profile.

5. Discussion of the Results

It is obvious that the light-induced lens is also liquid in the liquid suspension of QDs. Therefore, the photographs of Figures 2 and 3 show the kinetics and dynamics of the transformation of the wave surface of a liquid lens. The light structure of the "fountain" type has a well-defined gradation of optical density and, consequently, the real density of the suspension along the height of the fountain, for example, a 1600 ms frame in Figure 2. This may mean that a real fountain of this liquid occurs in a liquid medium when this liquid is illuminated by a focused laser beam.

A superfluid quantum liquid has a unique ability, called the "fountain effect", which has been repeatedly shown experimentally using the example of superfluid helium, and this is an autograph of superfluidity, as such. Figures 2 and 3 show that the light structure of the "fountain" type is always present in the converging optical beam and proceeds from the illumination area, which coincides with the axis of the input beam.

Frames 1-3 of Figure 4 show the stationary profile of the beam trace when the cuvette with the QDs was in the position z = -39z_0 (frame 1, the beam intensity is ~ 1 W/cm^2), z = -29z_0, (frame 2), and z = - 19z_0 (frame 3). Frame 4 shows the profile of the beam trace in the first 40 ms after the start of illumination of the medium for an intensity of about 100 W/cm^2, when the cuvette was located near the waist of the input beam. This frame shows that the "fountain" begins to emerge almost immediately after the start of lighting. The question is when the "fountain" begins to be visible in the pattern of the beam trace profile. The "fountain" pattern begins to be clearly visible when the upper half of the beam trace profile begins to flatten. The intensity distribution of the upper half of the beam trace profile "wraps up" beyond the horizon and exposes the "fountain" structure, which practically does not change its size. Good visibility of the "fountain" structure in frame 4 is due to the fact that the optical force of the light-induced lens becomes sufficient to form a wide external aberration ring of the beam trace profile already in these first 40 ms, then a dark spot is formed in the axial area of the input bunch. The originating structure "fountain" becomes clearly visible

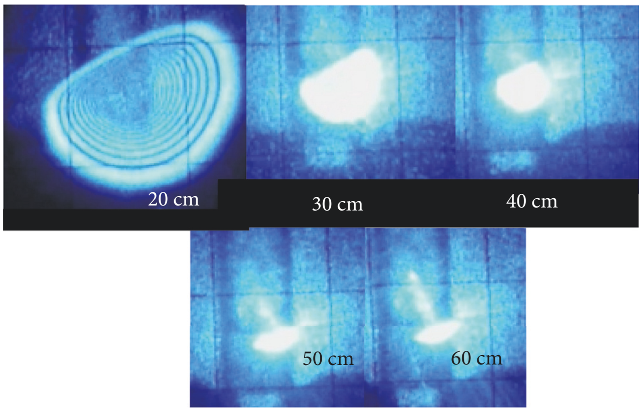

Figure 5: Transformation of the trace profile in a diverging beam with large detuning from the position of the beam waist and the emergence of a fountain from the axial region of the input beam.

in this aberration dark spot. This behavior of the "fountain" structure visibility substantiates the obvious conclusion that two physical processes or mechanisms form the pattern of the beam trace profile.

The first mechanism is a light-induced nonlinearity, the value of which depends on the intensity of the input beam; the second mechanism is due to the accumulation of quantum dots with a metastable exciton. The accumulation of quantum dots with a metastable exciton increases their number quantum dots in the illuminated volume of the colloid; in other words, the accumulation increases the number of qubits that can form the quantum state of quantum superposition.

All this indicates that in a real experiment one process masks another process. The first process is nonlinear self-focusing and defocusing of a focused optical beam in a nonlinear medium. The second process may be of a quantum nature, since it depends on the number of quantum particles and may be due to the formation of many-particle quantum superposition. The photographs of Figure 3 show that when the suspension is located behind the optical beam waist (a region of positive z values), there is no fountain in the beam trace profile. This was to be expected, since the fountain is caused by local heating of the superfluid liquid. A converging optical beam undergoes self-focusing when the QDs suspension is in the region of negative values of z (before the beam waist) and, thus, in a nonlinear medium there is a clearly localized region of maximum heating, which coincides with the axis of the input beam. When the suspension is in the positive range of z values (after the beam waist), the input beam experiences nonlinear defocusing and, thus, there is no local heating of the optical medium, since there is no dedicated heating region. The fountain is also missing. If the nonlinear medium is located far from the waist so that nonlinear defocusing is absent due to the small intensity of the input beam, the local heating region occurs, and it coincides with the axis of the input beam, where the intensity of the Gaussian laser beam is maximum. The local heating region occurs in the suspension of QDs and the "fountain" also occurs. This is well seen in the photos of Figure 5. We see that the size of the beam trace profile does not change when the detuning of the suspension position reaches 50-60 cm. This means that nonlinear defocusing is practically absent, whereas a well-defined fountain appears. The absence of defocusing indicates the leveling of all thermal and nonlinear processes that could take place. And the structure of the fountain type manifests itself especially clearly, which suggests the quantum nature of the detected phenomenon.

Another rather convincing autograph of a superfluid liquid is the Beaker effect, which is that the superfluid liquid "crawls" along the walls of the vessel in the form of a thin film. Once, the institute did not work on holidays. When I came to the laboratory, I saw that the cuvette with the QDs colloid is empty, and the dry QDs was all arranged in "piles" at the upper cut of the cuvette walls. I was surprised and thought, "Wow, what a high wettability this colloid QDs has." And only then, I realized that the superfluid colloid "crawled" along the walls of the cuvette out. The toluene solvent evaporated, and the QDs remained in the upper section of the cuvette walls. This experimental fact suggests that not only the superfluid properties of QDs suspension arise when illuminated by a laser beam, but ordinary daylight can turn a QDs suspension into a superfluid liquid at room temperature.

6. Conclusion

The concept of a macroscopic wave function as an array of entangled quantum states of quantum superposition was first proposed in this work. The formation of such a macroscopic wave function does not depend on thermal processes, which opens the way for the Bose-Einstein condensate to be obtained independently of the temperature of quantum objects, for example, a superfluid quantum liquid at room temperature. Semiconductor quantum dots, using the example of CdSe/ZnS, were used as quantum objects (qubit), which formed light-induced multiparticle quantum superposition. Experimental studies were performed with a suspension of CdSe/ZnS QDs in toluene at room temperature. The QDs suspension was illuminated by a focused CW-laser optical beam with a wavelength of 473 nm and with a power of up to 30 mW. The results of the experiments showed two autographs characteristic of a superfluid liquid: the flow of fluid from the area of local heating and complete "creeping out" of the QDs suspension, like a thin film, from a cuvette along its walls.

The principal difference of this work from other works with a similar theme, for example [9], is that in this work Bose-Einstein realized condensation, regardless of both temperature and the mass of quantum objects. The mass of a quantum dot exceeds the mass of an electron by many orders of magnitude, whereas an exciton-polariton has a mass that has many orders of magnitude smaller than the mass of an electron. Condensate exciton-polariton [9] is essentially a quantum liquid of light, which is obtained according to the classical physics of Bose-Einstein condensation. The theory of quantum liquid light, regardless of temperature, is developed based on the coincidence of the recording forms of the paraxial nonlinear Schrödinger equation for the propagation of an optical beam in a nonlinear medium (4) by writing the Gross–Pitaevskii equation (5) [5].

$$2ik\frac{\partial A}{\partial z} = -\nabla_T^2 A - \frac{2k^2 n_2}{n_0} |A|^2 A \tag{4}$$

Here A is the amplitude of the electric field of the light wave and z is the direction of propagation of the optical beam. In other words, this equation describes the evolution of the amplitude of the electric field as it propagates in a nonlinear medium and not the evolution in time of wave functions, like the Gross–Pitaevskii equation. The theory of a quantum superfluid liquid is based on the Gross–Pitaevskii equation [7, 8]. This equation describes the evolution of the Bose-Einstein wave function of the condensate Ψ of N particles that have a macroscopic wave function: $\Phi(x_1, x_2, \ldots x_N)=\Pi_N \Psi_i(r_i)$.

$$i\hbar\frac{\partial \Psi(x)}{\partial t} = \left(-\frac{\hbar^2}{2m}\nabla^2 + V(x) + g|\Psi(x)|^2\right)\Psi(x) \tag{5}$$

Here Ψ_i is the wave function of a single particle; the first term in the right-hand side is the kinetic energy of each particle. The second term describes the boson-boson interaction through the V-potential, m is the particle mass, g is the coupling constant, so $g=4\pi\hbar^2 a_s/m$, and as is the length of diffusion between particles, $|\Psi(x)|^2$ is the density of particles. This equation contains classical quantities such as mass, time, potential, and diffusion length. Therefore, this equation describes the behavior of an ensemble of quantum particles in classical space, where the macroscopic wave function is the product of the wave functions of individual particles. This paper offers another Bose-Einstein condensation physics, in which a macroscopic wave function contains 2^N entangled wave functions as a result of creating a quantum state of quantum superposition. The quantum state of quantum superposition is the result of the interaction of two-level quantum objects and does not depend on classical quantities such as mass, temperature, and time, which makes it possible to create Bose-Einstein condensation regardless of these quantities, for example, creating a superfluid quantum fluid. Obviously, the creation of Bose-Einstein condensate, not burdened by temperature dependence, allows you to actually create very simple devices and devices based on superfluid quantum liquid.

Data Availability

All experimental data used to support the results of this study are contained in video files with the author of the article. Copies of this data can be obtained for free upon request at anaisaev@yandex.ru.

Conflicts of Interest

The author declares that they have no conflicts of interest.

Supplementary Materials

Video file Video 1 represents the transformation of the pattern of the beam trace profile in real time, when the cuvette with the colloid was in the z = -49 z0 position. Video file Video 2 represents the transformation of the pattern of the beam trace profile in real time, when the cuvette with the colloid was in the z = -39 z0 position. *(Supplementary Materials)*

References

[1] P. Kapitza, "Viscosity of liquid helium below the λ-point," *Nature*, vol. 141, p. 74, 1938.

[2] J. F. Allen and A. D. Misener, "Flow of liquid helium II," *Nature*, vol. 141, p. 75, 1938.

[3] M. H. Anderson et al., "Observation of Bose-Einstein condensation in a dilute atomic vapour," *Science*, vol. 269, p. 198, 1995.

[4] A. Amo, J. Lefrère, S. Pigeon et al., "Superfluidity of polaritons in semiconductor microcavities," *Nature Physics*, vol. 5, no. 11, pp. 805–810, 2009.

[5] I. Carusotto and C. Ciuti, "Quantum fluids of light," *Reviews of Modern Physics*, vol. 85, pp. 299–366, 2013.

[6] I. Carusotto and C. Ciuti, "Probing microcavity polariton superfluidity through resonant rayleigh scattering," *Physical Review Letters*, vol. 93, Article ID 166401, 2004.

[7] D. Sanvitto, S. Pigeon, A. Amo et al., "All-optical control of the quantum flow of a polariton condensate," *Nature Photonics*, vol. 5, no. 10, pp. 610–614, 2011.

[8] A. Amo, S. Pigeon, D. Sanvitto et al., "Polariton superfluids reveal quantum hydrodynamic solitons," *Science*, vol. 332, no. 6034, pp. 1167–1170, 2011.

[9] G. Lerario, A. Fieramosca, F. Barachati et al., "Room-temperature superfluidity in a polariton condensate," *Nature Physics*, vol. 13, no. 9, pp. 837–841, 2017.

[10] A. Isaev, "Cumulative electronic non-linearity of CdSe/ZnS quantum dots," *Journal of Physics D: Applied Physics*, vol. 46, no. 21, Article ID 215301, 2013.

[11] A. A. Isaev, "Interference propagation of laser beams in colloids of quantum dots," *Engineering Physics*, no. 8, pp. 41–50, 2013.

[12] A. G. Vitukhnovskii, A. A. Isaev, and V. S. Lebedev, "Light-induced nonlinearity of CdSe/ZnS quantum dots with a millisecond relaxation time," *Nanotechnologies in Russia*, vol. 3, no. 11-12, pp. 158–165, 2008.

[13] A. S. Selyukov, A. A. Isaev, A. G. Vituknovsky et al., "Nonlinear optical response of CdSe nanocrystals in planar and spherical geometry," *FTS*, no. 7, 2016.

[14] F. T. Rabouw, M. Kamp, R. J. A. Van Dijk-Moes et al., "Delayed exciton emission and its relation to blinking in CdSe quantum dots," *Nano Letters*, vol. 15, no. 11, pp. 7718–7725, 2015.

[15] J. Hoy, *Energetic and Dynamics in Quantum Confined Semiconductor Nanostructures [Dissertation, Doctor of Philosophy in Chemistry]*, Washington University in St. Louis, 2013.

[16] R. W. Boyd, *Nonlinear Optics*, Academic Press, New York, NY, USA, 3rd edition, 2007.

[17] M. Sheik-Bahae and M. P. Hasselbeck, "Third order optical nonlinearities," *OSA Handbook of Optics*, vol. IV, Chapter. 17, 2000.

[18] M. Born and E. Wolff, *Principles of Optics*, McGraw-Hill, New York, NY, USA, 1959.

[19] S. A. Akhmanov, D. P. Krindach, A. P. Sukhorukov, and R. V. Khokhlov, “Nonlinear defocusing of laser beams,” *Journal of Experimental and Theoretical Physics (letters)*, vol. 6, pp. 209–513, 1967.

[20] S. A. Akhmanov, D. P. Krindach, A. V. Migulin et al., “Thermal self-actions of laser beams,” *IEEE Journal of Quantum Electronics*, vol. QE-4, no. 10, pp. 568–575, 1968.

[21] J. R. Whinnery, D. T. Miller, and F. Dabby, “Thermal convection and spherical aberration distortion of laser beams in low-loss liquids,” *IEEE Journal of Quantum Electronics*, vol. QE-3, no. 9, pp. 382-383, 1967.