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## On the Maximum Size of a Neutron Droplet in an Ultracold Neutron Gas

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**On the Maximum Size of a Neutron Droplet  
in an Ultracold Neutron Gas**

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### **О максимальном размере нейтронной капли в ультрахолодном нейтронном газе**

Развито представление о нейтроне как трансляционно-инвариантном поляроне в мезонном поле. При этом динейтроны рассматриваются как спаренные состояния таких нейтронных поляронов. Подчеркнута роль мезонного поля в формировании столкновительного механизма образования динейтронов в бесстолкновительном нейтронном УХН газе. Теоретически подтверждена оценка времени образования динейтрона (27 часов), полученная ранее из сравнения времени жизни нейтрона в пучковых и бутылочных экспериментах.

Рассмотрен бозе конденсат из динейтронов, существование которых в свободном виде невозможно. Проведено моделирование динамики образования спаренных состояний в ловушке с УХН. Характерный размер капли из спаренных нуклонных состояний составляет 10 нанометров. Обсуждаются возможности экспериментальной проверки теории.

**Ключевые слова:** мезонная шуба полярона, термодинамическое равновесие в УХН, датчики динейтронов, нейтронный бозе-конденсат УХН, нейтронная молекула

*Victor Dmitrievich Lakhno*

### **On the Maximum Size of a Neutron Droplet in an Ultracold Neutron Gas**

The concept of the neutron as a translationally invariant polaron in a meson field is developed. Dineutrons are considered as paired states of such neutron polarons. The role of the meson field in the formation of the collisional mechanism of dineutron production in collisionless neutron UCN gas is emphasized. The estimate of the dineutron formation time (27 hours), obtained earlier from a comparison of the neutron lifetime in beam and bottle experiments, has been theoretically confirmed.

A Bose condensate of dineutrons, which cannot exist in free form, is considered. The dynamics of paired state formation in a trap with ultracold neutrons is simulated. The characteristic size of a droplet of paired nucleon states is 10 nanometers. Potential for experimental verification of the theory is discussed.

**Key words:** polaron meson coat, thermodynamic equilibrium in UCNs, dineutron detectors, UCN neutron Bose condensate, neutronic molecule.

# 1. Introduction

Currently, polaron models, originally used in condensed matter physics, are beginning to be used with great effectiveness in elementary particle physics. For example, the quark polaron model [1], which is based on the theory of translationally invariant (TI) polarons [2], has successfully explained the reason for the large mass of nucleons consisting of quarks whose mass is several orders of magnitude smaller than the nucleon mass. The polaron theory can explain the nature of quark confinement, since it leads to the idea that it is impossible to separate particles in a bound bipolaron state into individual polarons [3]. The TI theory of excitons in a phonon field [4] provides an explanation for the nature of the asymptotic freedom of quarks, since an increase in the force of interaction with the phonon field leads to the limit of a free exciton, that is, to the limit of weak coupling.

Earlier [5], [6] we examined in detail the case of the possible existence of a neutron Bose condensate in an ultracold neutron gas (UCN), in which the role of bosons was played by dineutrons, considered as bipolaron bound states of two neutrons with a non-zero positive binding energy  $E_b$ . In this case, the size of the dineutron and the dineutron Bose condensate is determined by the magnitude of the binding energy associated with their size  $\xi$  and mass  $M$  by the relation  $E_b \approx \hbar^2 / M\xi^2$ .

The presence of even weakly bound free but stable neutron formations would greatly affect the lifetime of the universe and, apparently, they do not occur in nature under ordinary conditions. Such formations, however, are realized in neutron stars and in the halos of some nuclei. In [5], [6], the possibility of dineutron formation in an ultracold neutron gas was also considered in order to explain the anomaly in the storage time of such a gas in a UCN trap. In this paper, we will discuss in more detail the formation of bound neutron states and the formation of a dineutron Bose condensate in traps in the case of  $E_b=0$ , that is, when, according to the generally accepted opinion, a stable dineutron does not exist in a free state.

## 2. A neutron droplet in the absence of bound dineutron states

The problem under consideration is similar to the problem of the formation of multipolaron states in a condensed medium. In condensed media, the formation of multipolaron states is complicated by the existence of a polaron charge, the presence of which prevents the formation of polaron droplets in them (as an example of a multipolaron composed of magnetic polarons, one can cite the possibility of the formation of ferromagnetic regions in antiferromagnets stabilized by electron droplets, taking into account the polaron effect [7], which was considered in the works of Nagaev [8]). Since neutrons do not possess a charge, the formation of multipolaron droplets from neutrons in a meson field can be facilitated (the possibility of the formation of a pion condensate in nuclei, considered by Migdal [9], also belongs to this range of problems).

If we consider neutrons as non-interacting with the meson field (and other fields), then the Hamiltonian of the system will be additive with respect to these fields.

Formally, in this case, the meson field can be removed by setting the meson frequencies and the interaction constant equal to zero (the meson frequencies are assumed to be zero because their contribution to the TI polaron spectrum is not zero even at  $g=0$ , where  $g$  is the nucleon-meson coupling constant [2]). This is the case of a free neutron field. If paired neutron states in such a field are considered as bosons, then their Bose condensate has the Einstein temperature of Bose condensation:  $T_c = T_c(0)$ .

For nonzero (arbitrarily small)  $g$ , the temperature of the Bose condensate changes radically. This is due to the fact that, for nonzero  $g$ , both subsystems become nonequilibrium with respect to the formation of polarons (bipolarons) with the  $T_c$  of their Bose condensate equal to [5], [6]:

$$T_c(f) = \left( F_{3/2}(0) / F_{3/2}(f) \right)^{2/3} T_c(0) \quad (1)$$

$$F_{3/2}(f) = \frac{2}{\sqrt{\pi}} \int_0^\gamma \frac{t^{1/2} dt}{e^{t + \sqrt{f^2 + 2Mft/\mu}} - 1}, \quad T_c(0) = 3,31 \frac{n^{2/3}}{M}, \quad \gamma = \frac{\kappa}{T_c}$$

where  $f = \mu/T_c = 1,566 \cdot 10^{12} K/T_c$ ,  $\mu$  is the meson mass,  $M$  is the mass of a binucleon (it is assumed that  $\hbar = 1$ , the speed of light is  $c = 1$ , the temperature  $T$  is measured in Kelvin:  $K$ ). With such a combination of Fermi and Bose systems, a Bose condensate is always formed in the ultra-low temperature limit, since the ground state of the Bose condensate at  $T=0$  will have zero, that is, the lowest, energy. The particles that make up such a Bose condensate will be TI bipolarons (from now on, we will omit the word "neutron" in the terms "neutron polaron" or "bipolaron"). This will be the case even if the formation of a bipolaron is less energetically advantageous than the formation of two unbound polarons, since only bipolarons (generally multipolarons, such as tetra-neutrons or hexa-neutrons, with integer spin) are capable of forming a Bose condensate.

In the case of a dense neutron medium (neutron stars), both polarons and bipolarons have a size of the order of the Compton length of a meson (the size of the meson coat of a polaron).

In neutron stars, the characteristic distance between neutrons is also of the order of the Compton length. This means that the neutron gas in a star is ultradense.

A completely different situation occurs in the case of an ultracold neutron gas confined in a material trap. The distance between neutrons in real traps is about 0.1 cm or more, while the characteristic size of a bipolaron Bose condensate is very small and, as will be shown below, is of the order of tens of nanometers. This means that an entirely new type of low-density neutron Bose condensate is possible, which can arise in an ultracold neutron gas confined in a material trap. As shown in [5], [6], formula (1) yields a very high  $T_c$  even for ultra-low concentrations of paired neutrons. In reality, according to [5], [6],  $T_c$  is limited by the depth of the optical potential of the trap, i.e., the maximum value is  $T_c = \kappa$  and is approximately equal to  $10^{-3}$  K.

In the absence of stable dineutrons, the pairing of neutrons that do not interact with each other will occur at a temperature of their Bose condensate equal to:

$$T_c = 0.218E_F, \quad (2)$$

provided that  $T_c$  does not exceed  $\kappa$ . The value of  $T_c$ , determined by (2), corresponds to the temperature of a neutron Fermi gas in which all neutrons have passed into a paired state and formed a Bose gas.

In fact, the Fermi energy  $E_F$  for the concentrations attainable in a trap is so low that a degenerate neutron gas, much less its Bose-Einstein condensate, cannot be experimentally realized. The situation can change radically if a neutron droplet with a neutron concentration many orders of magnitude higher than the neutron concentration in a UCN trap were to form in the neutron gas. We will consider this case below.

### 3. Coherence length of the TI bipolaron Bose condensate

The interaction between two neutrons, each occurring in a delocalized state and described by a plane wave, does not result in their localization, but rather in their correlated motion, which is described by the correlation length  $\xi$ , over which they sense each other. The correlated motion of two TI polarons is a TI bipolaron. For this, it is necessary that the average distance between the neutrons be less than  $\xi$ . This is possible if the concentration of neutrons in the trap is sufficiently high. This situation can be realized with the formation of a neutron droplet in the UCN gas. Such a droplet can be said to be formed by TI bipolarons from neutrons. For this reason, we need to consider a boson gas consisting of TI bipolarons forming a neutron droplet.

In quantum mechanics, the many-particle and field descriptions of a gas of TI bipolarons are equivalent. The many-particle density matrix for  $n$  particles has the form:

$$g(R_1, \dots, R_n; R'_1, \dots, R'_n) = \sum_k n_k \Psi_k^*(R_1, \dots, R_n) \Psi_k(R'_1, \dots, R'_n). \quad (3)$$

In the case of an ideal Bose gas in the absence of interaction, its wave function has the form:

$$\Psi_k(R_1, \dots, R_n) = \prod_i^n \varphi_k(R_i) \quad (4)$$

and the calculation of a multiparticle matrix is reduced to the calculation of a single-particle matrix:

$$g(R_1, R_2) = \sum_k n_k \varphi_k^*(R_1) \varphi_k(R_2) \quad (5)$$

In the field description, the density matrix has the form:

$$g(\mathbf{R}, \mathbf{R}') = \langle \hat{\Psi}(\mathbf{R}), \hat{\Psi}^+(\mathbf{R}') \rangle, \quad (6)$$

where  $\hat{\Psi}(\mathbf{R})$  is the field operator of the system under consideration, the brackets  $\langle \dots \rangle$  in (6) mean averaging over a grand canonical ensemble. Decomposing the field operator into a series of plane waves:

$$\hat{\Psi}(\mathbf{R}) = \frac{1}{\sqrt{V}} \sum_k \hat{a}_k e^{ik\mathbf{R}}, \quad (7)$$

where  $\hat{a}_k$  is the operator of a particle annihilation in state  $k$ ,  $V$  is the volume of the system, from (6), (7) we obtain:

$$g(\mathbf{R}, \mathbf{R}') = g(\mathbf{R} - \mathbf{R}') = \frac{1}{\sqrt{V}} \sum_k \langle \hat{n}_k \rangle e^{ik(\mathbf{R} - \mathbf{R}')}, \quad (8)$$

where  $\langle \hat{n}_k \rangle = n_k$  is the Bose distribution function of the gas. Thus, the description of the quantum field is equivalent to a description based on a single-particle density matrix, which gives an idea of the spatial and temporal behavior of the condensate. In the case of a gas of TI bipolarons, both the wave functions of individual neutrons (TI polarons) and the wave functions of the TI bipolarons themselves, described as particles whose coordinates are determined by the position of their centers of mass  $R_i$ , are delocalized. In this case, the correlation length  $\xi$  determines the characteristic size of the distribution of bipolarons in a gas of TI bipolarons.

In quantum statistical mechanics, the off-diagonal elements of the density matrix determine the degree of coherence between different quantum states.

In the case of a Bose gas under consideration, its state is described by plane wave functions of particles with momentum  $k$ :  $\varphi_k(R_i) = e^{ikR_i}/\sqrt{V}$ , where  $R_i$  are the coordinates of the  $i$ -th particle. Accordingly, the off-diagonal element of the density matrix, which is a key parameter for understanding the long-range order, is determined by the expression

$$g(R_1, R_2) = \sum_k n_k \varphi_k^*(R_1) \varphi_k(R_2), \quad n_k = \{\exp[(E_k - \mu_{chem})/T] - 1\}^{-1}, \quad (9)$$

where  $n_k$  is the Bose distribution function of the gas particles, and  $\mu_{chem}$  is the chemical potential. Separating the contributions of the condensate with  $k=0$  from the temperature component, we can rewrite this expression as

$$g(R_1, R_2) = \frac{N_0}{V} + \frac{1}{(2\pi\hbar)^3} \int d^3k \frac{\exp[ik(R_1 - R_2)/\hbar]}{\exp[(E_k - \mu_{chem})/T] - 1}, \quad (10)$$

where  $N_0$  is the number of particles in the Bose condensate. The energy of the TI bipolaron  $E_k$ , included in (10), according to [5], has the form

$$E_k = [\Delta_k + E_{bp} + k^2/2M], \quad k > 0, \quad (11)$$

where  $E_{bp}$  is the energy of the bipolaron ground state,  $\Delta_k$  has the meaning of the value of the superconducting gap:

$$\Delta_k = \kappa. \quad (12)$$

As noted above, in the case of a neutron gas in a trap under consideration, the role of the trap is played by the value of the optical potential of the trap. Using (10)-(11), for  $g_R$  we obtain:

$$g(R) = \frac{N_0}{V} + \frac{1}{l_T^3} \sum_{j=1}^{\infty} \exp[-j(E_{bp} + \kappa - \mu_{chem})/T - \pi R^2/jl_T^2] j^{-3/2}, \quad (13)$$

$$l_T = \hbar \left( \frac{2\pi}{MT} \right)^{1/2}, \quad (14)$$

where  $R = |R_1 - R_2|$ . In the case of  $R \gg l_T$ :

$$g(R) = \frac{N_0}{V} + \frac{2}{l_T^2 (2\pi\xi R)^{1/2}} K_{1/2} \left( \frac{R}{\xi} \right), \quad (15)$$

where  $K_\mu$  is the modified Bessel function,

$$\xi = \frac{l_T}{\left( 2\pi^{1/2} \sqrt{(E_{bp} + \kappa - \mu_{chem})/T} \right)}. \quad (16)$$

The quantity  $\xi$  has the meaning of the coherence length. Taking into account (16), the expression for  $\xi$  can be represented as:

$$\xi = \frac{\hbar}{\sqrt{2M(\kappa + E_{bp} - \mu_{chem})}}. \quad (17)$$

From (17) it follows that the coherence length of the TI bipolaron gas at  $T \leq T_c$  does not depend on  $T$ . At  $T \geq T_c$  the temperature dependence of the coherence length,

according to (17), is determined by the temperature dependence of the chemical potential  $\mu_{chem}(T)$ . At  $T = T_c$ , when  $\mu_{chem} = E_{bp}$ , the coherence length  $\xi$  of the ideal Bose gas (IBG), corresponding to  $k=0$ , becomes infinite and remains so at  $T \leq T_c$ .

Unlike IBG, the coherence length of the TI bipolaron gas is finite at  $T \leq T_c$  and is equal to:

$$\xi = \hbar / \sqrt{2\kappa M}. \quad (18)$$

At  $T \geq T_c$  the coherence length remains finite and is determined by (17) up to the temperature of the existence of the pseudogap phase  $T^*$ , at which the decay of TI bipolarons occurs.

Note that for  $R \gg \xi$  according to (15),  $g(R)$  has the form:

$$g(R) = 1/l_T^2 R \exp(-R/\xi). \quad (19)$$

For a material trap whose optical potential is  $\kappa = 10^{-3}$  K,  $M = 2m_n$ , where  $m_n$  – is the neutron mass, for the coherence length  $\xi$  at  $T \leq T_c$  from (18) we obtain:  $\xi \approx 10$  nm. The result obtained corresponds to the calculations of the characteristic size of the state of one neutron ( $\approx 10$ nm), trapped by the optical potential of the trap [10]. The authors of [10] suggested using their approach to construct neutron molecules. Our calculation of the correlation length allows us to conclude that the size of the simplest molecule of two neutrons, that is, a dineutron, will have a characteristic size  $\xi$  and a binding energy  $\approx 10^{-7}$  eV.

In [6], we determined the dineutron formation time in a UCN trap. Clearly, for such formation to occur, the "collision" frequency in the neutron gas must be greater than the inverse of the formation time. We assume that the formation of a dineutron can occur only if the distance between neutrons does not exceed the correlation length  $\xi$ .

For the collision frequency  $\nu = \sigma v n$ , where  $n \approx 10^4 \text{ cm}^{-3}$  the neutron concentration in UCN,  $v \approx 5$  m/sec,  $\sigma \approx 4\pi\xi^2$  and  $\xi = 40$  nm, corresponding to the helium trap (see Appendix), we obtain  $\nu \approx 10^{-4} \text{ sec}^{-1}$ . Thus, the corresponding

collision time  $\tau \approx 2.8$  hours is an order of magnitude shorter than the time of formation of a dineutron equal to 27 hours, obtained in [6] based on a comparison of experimental data on the storage time in beam and bottle experiments. It follows that the above-mentioned condition for the formation of a paired state is satisfied with a good margin.

When dineutrons are formed in a neutron gas, they are not in equilibrium and, under the influence of the gravitational field, fall to the bottom of the trap, accumulating there at the deepest point of the trap potential relief. A dineutron droplet will begin to form when the dineutron concentration at the bottom reaches  $1/\xi^3$ , that is, at a concentration of about  $10^{18}$  dineutron/cm<sup>3</sup>. The results of modeling the dynamics of the formation of a neutron pair in UCN gas are presented in the Appendix.

If a free dineutron is a stable particle, we can estimate the time it takes for a neutron droplet of size  $\xi$  to form a neutron point droplet of size  $\lambda = \hbar/mc$  which is the meson Compton wavelength. In this case, the above estimate for  $\nu$  will change to the expression for  $\nu_\lambda$ , where  $\nu_\lambda$  is the frequency of neutron collisions in a point droplet, which will be equal to:

$$\nu_\lambda = \frac{\lambda^2}{\xi^2} \cdot \frac{n_\xi}{n} \nu$$

where  $n_\xi$  — is the concentration of dineutrons in a droplet:  $n_\xi \approx 10^{26}$  n/cm<sup>3</sup>,  $\lambda = 1,46 \cdot 10^{-13}$  cm. The estimate of  $\nu_\lambda$  for the above parameter values yields  $\nu_\lambda \approx 10^8$  sec<sup>-1</sup>. Thus, if a stable compact dineutron of size  $\lambda$  existed, its formation in the droplet would be very fast: of the order of a hundredth of a microsecond. Thus, the limiting time in this case would be the time of formation of an extended neutron droplet.

## 4. Discussion

In this paper, we consider the maximum size of a neutron Bose-Einstein condensate droplet, which is determined by the correlation length  $\xi$ . For larger droplets, the diametrically opposed neutrons in the droplet are no longer correlated and can freely escape, maintaining the droplet's size. The center of gravity of such a droplet will coincide with the center of gravity of each of the dineutrons in it and will be located

at the point of the minimum optical potential at the bottom of the trap. The lifetime of such a clump of neutron matter in the trap may exceed the beta decay time of a neutron (the arguments for this assertion are presented in [6]). The peculiarity of the considered neutron Fermi system in comparison with the electron one, which forms a Bose condensate in superconductors, is the impossibility of the superconducting condensate in the electron Fermi system to assemble into a point droplet, since this will be prevented by the Coulomb repulsion of Cooper pairs or bipolarons forming a condensate. The closest case to the issue under consideration is the formation of Bose-Einstein condensate droplets, experimentally observed in traps with ultracold atoms [11], [12].

The concept of a dineutron as a TI bipolaron, that is, two neutrons bound together by a meson field, differs radically from the previously held view of it as a compact elementary particle. In the absence of an external potential, both neutrons in such a formation are completely delocalized, although their motion is correlated, as in a Cooper pair. For this reason, neutron detectors will perceive the neutrons that make up the dineutron as separate ones. In nuclear decay experiments, they are detected as pairs of particles whose momenta have a similar direction. During the decay of trapped dineutrons, the neutrons formed as a result of the decay will have opposite momenta and spins. In this case, detector systems surrounding the target (trap) on all sides should be used. When two detectors located opposite each other are triggered simultaneously, this signals the detection of an antiparallel pair.

This conclusion is valid only in the case considered here, where a stable bound dineutron state in a free form is absent. The considered scenario of the formation of bound neutron states is similar to the formation of Cooper pairs. When interpreting Cooper pairing, one usually uses a qualitative representation of an electron in a crystal, which, when moving, leaves behind a phonon tail, that is, a region of the crystal deformed by an electron. This region is sensed by another electron, leading to their mutual attraction. In the case of a gas of neutron TI bipolarons under consideration, the

neutrons in them are delocalized throughout the entire volume of the trap and correlate with each other only at distances not exceeding  $\xi$ .

In the case of magnetic neutron traps, the role of  $\kappa$  is played by the energy of the magnetic moment of the neutron in the magnetic field, which holds the neutrons in the trap. In the classical consideration of a neutron gas as collisionless, as early as 1906 Poincare showed that in such a gas placed in a rectangular box with mirrored walls, regardless of its initial distribution, the box will be uniformly filled with this gas over time [13]. The formation of dineutrons in a magnetic trap will be difficult in this case, since it is associated with the need to flip the spin to form a singlet state. The formation of a neutron droplet, as shown in [6], is impossible in this case.

If the free dineutron is stable (i.e., has a positive binding energy) and its correlation length is of the order of the Compton length, then the condensate will collapse into a droplet with a size of the order of this length. The formation of such a condensate will likely lead to its stabilization relative to beta decay, and the detectors will detect nothing. In this case, however, the neutron droplet may escape the trap [6]. For this reason, it is better to conduct such experiments under microgravity conditions. The formation of a dense neutron droplet is also possible when an attractive interaction exists between neutron pairs that does not lead to their bound state (negative binding energy) due to the instability of the Bose condensate with such an interaction. If there are a large number of neutrons in the trap, due to the finiteness of the correlation length, the neutrons will no longer fit into one droplet, forming a fragmented Bose gas from individual droplets, each of which can be considered as a single massive Bose particle. If phase coherence is established between such massive bosons, they can also form a single Bose condensate. This scenario is unlikely to be realized under terrestrial conditions, however it may be of interest for describing the Bose condensate in neutron stars.

Currently, an experiment (BL3) is planned in Gaithersburg (USA) to determine the lifetime of a neutron in a beam experiment with significantly higher accuracy than previous experiments. If this confirms the value of the neutron lifetime obtained in

previous beam experiments, then the solution to the problem of the neutron anomaly in bottle experiments will require a choice between neutrons escaping the trap into dark matter or the formation of dineutrons within it. If this confirms the value of the neutron lifetime obtained in previous beam experiments, then the solution to the problem of the neutron anomaly in bottle experiments will be related to the need to choose between the escape of neutrons from the trap into dark matter or the formation of dineutrons in it. After recording the results that unequivocally confirm the existence of the neutron anomaly, the most pressing task will be to record the existence of dineutrons in bottle experiments.

## 5. Appendix. Kinetics of dinucleon formation in UCN gas

Let us consider a UCN gas in a trap. Neutrons have a finite lifetime  $\tau$ . When two neutrons collide with probability  $p$ , a bound pair is formed. If the neutrons in a dinucleon do not change their lifetime, then the dinucleon lifetime will be  $\tau_d = \tau/2$ . The change in the neutron and dineutron concentration  $n_d$  is described by the system:

$$\begin{cases} \frac{dn}{dt} = -\frac{n}{\tau} - \kappa p n^2 \\ \frac{dn_d}{dt} = \frac{1}{2} \kappa p n^2 - \frac{2n_d}{\tau} \end{cases}$$

where  $\kappa = \sigma v$  is the rate constant for binary collisions. For a rarefied gas, where the decay rate dominates the collision rate, the solution for the number of dineutrons is (Fig. 1):

$$n_d = \frac{1}{2} \kappa p n_0^2 t \cdot e^{-2t/\tau}, \quad n(t) \approx n_0 e^{-t/\tau}$$

The maximum number of dineutrons  $n_{d \max}$  is reached at the moment:

$$t_{\max} = \tau/2, \quad n_{d \max} = \kappa n_0^2 \tau / 2e, \quad e = 2,718$$

For a neutron gas in a helium trap with parameters  $\sigma = 4\pi\xi^2 = 2 \cdot 10^4 \text{ nm}^2$  - neutron-neutron scattering cross-section,  $v = 5 \text{ m/sec}$ , concentration  $n_0 = 10^4 \text{ cm}^{-3}$ ,  $\kappa = \sigma v = 10^{-7} \text{ cm}^3/\text{sec}$  (one collision every 2.7 hours),  $\kappa n_0 = 10^{-4} \text{ sec}^{-1}$ , the probability of dineutron formation in each collision  $p = 1$ , we obtain:

$$\frac{n_{d \max}}{n_0} = \frac{\kappa n_0^2 \tau}{2e} \approx 16.25\%$$

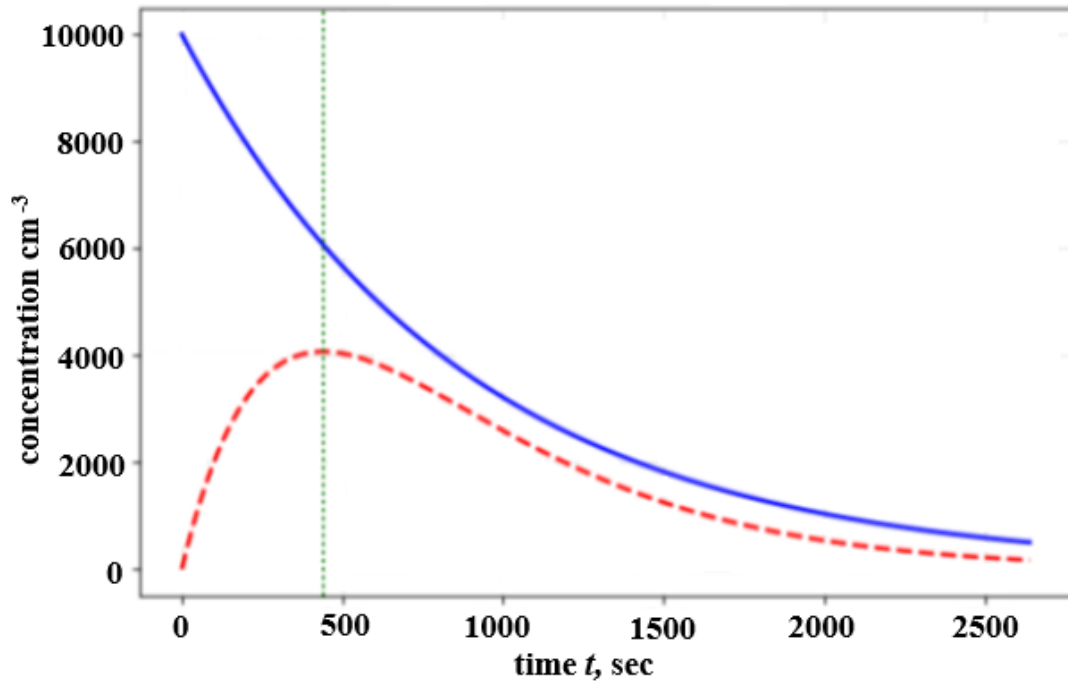


Fig.1 Neutrons in the trap decrease exponentially with time (blue line); initially, there are no dineutrons, but the high neutron density causes them to form rapidly (red line). The maximum dineutron concentration is reached at  $t_{max} = \tau/2 = 440$  sec and is equal to  $\approx 813$  dineutrons/cm<sup>3</sup>, the total fraction of dineutrons at maximum  $\approx 16\%$ .

The critical density of the state at which, at the moment of maximum, exactly half of the undecayed neutrons are in the paired state ( $2n_d = n$ ) will be

$$n_{crit} = \frac{1}{2p\kappa\tau}$$

For the specified parameters:  $n_{crit} \approx 5.68 \cdot 10^4$  cm<sup>-3</sup>. Thus, in a system with a finite lifetime of the components, the maximum in pairing always occurs after a time equal to half the average lifetime of a particle, and the amplitude of this maximum depends linearly on the gas density and the pairing probability.

If  $p \neq 1$ , then the time to reach the maximum will not change. The relative number of dineutrons will decrease by a factor of  $1/p$ .

If at  $p = 1$  we had  $n_{d\ max}/n_0 = 16,26\%$ , then with probability  $p$  the proportion will be  $n_{d\ max}/n_0 = 0,1626p$ . For example, if every tenth pair pairs ( $p = 0.1$ ), then the maximum will be only  $1,626\%$

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