This result, together with the expressions (A.8), (A.9), and (A.11) for the matrix $E_{n+\alpha,n+\beta}$ is nothing other than the formula (3.4) itself, except that it is for the "case $m+1$," with the solution g_{n+m}, f_{n+m}, ψ_{n+m} being obtained from g_{n-1}, f_{n-1}, ψ_{n-1} by adding $m+1$ solitons to the latter. This analysis completes the proof that Eq. (3.4) is valid.

[1]A system of units is used in which the speed of light is equal to unity. The interval is written in the form $-ds^2=g_{ik}dx_i dx_k$, where g_{ik} has the signature $-+++$.

[2]We may indicate that the formal transformations from the variables ζ, η, α, β and matrices A, B which we used previously to the variables ρ, z and matrices U, V of the present paper are of the form $\zeta=(z+i\rho)/2$, $\eta=(z-i\rho)/2$, $\alpha=i\rho$, $\beta=z$, $A=-U-iV$, $B=-U+iV$.

[3]Nevertheless we can obtain physical solutions with an odd number of solitons, but for this it is necessary to take a background solution with a nonphysical signature, for which $\det g_0=\rho^2$.

[4]We point out that the indicated choice of "signs" here has a precise meaning only for sufficiently large positive values of the variable r and real values of the constants w_1 and w_2. In the general case there is only a choice of one branch or the other of the solution of the quadratic equation (2.11).

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Search for unusual decays of superdense nuclei using two-meter hydrogen and propane bubble chambers

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Preliminary results are reported on the determination of the upper limits of the cross sections for production of superdense nuclei, by detection of their unusual decays occurring with times in the millisecond range. A special mode of bubble-chamber operation is proposed. It is shown that by use of this technique it is possible to determine comparatively simple cross sections at the level 10^{-33}–10^{-35} cm^2 per nucleus.

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In recent years, especially with the appearance of A. B. Migdal's theory of the pion condensate, great interest has arisen in the search for superdense nuclei. It is expected that they can have a very large binding energy, and therefore it is possible in principle to observe the decays of such nuclei, which occur with a large energy release. On the other hand it is known that for decays of ordinary nuclei in the case when the decay electrons are relativistic we have the relation[1] $\tau_c\sim 1/E_{max}^5$, where τ_c is the lifetime of the nucleus and E_{max} is the maximum energy of the decay electrons. If we assume that this relation will be satisfied also for decays of superdense nuclei, then for a maximum decay-particle energy $E_{max}=18$ MeV, τ_c will be 1.6 times less than the lifetime of N_7^{12} and will amount to ≈6.7 nsec, and for $E_{max}=36$ MeV $\tau_c=0.2$ nsec, etc. Measurement of these lifetimes and decay energies can be carried out very satisfactorily by means of bubble chambers.

The advantages of the bubble-chamber technique are a 4π geometry, the possibility of detecting decay particles of various types ($e^\pm$, γ, heavier particles), the accurate measurement of their energies, and also the possibility of observing "explosions" of superdense nuclei which result in stars recorded in the chamber. A major advantage of this experimental arrangement is the absence of any ordinary physical process imitating the effect.

Up to the present time there has been no experimental proof of the existence of superdense nuclei. Kulikov and Pontecorvo[2] presented some data obtained by an electronic technique on determination of the upper limits of the cross sections for production of superdense nuclei, as a function of their lifetime. It is evident from these data that the region of lifetimes $\tau_c\leq 5$ msec has not yet been investigated.

The experiments described in the present paper were intended to search for unusual decays, which can arise from superdense nuclei, with energy more than 16.4 MeV (the maximum energy of the decays known up to this time) and occurring with lifetimes 0.5–1000 msec.

The essential features of the technique used are as follows. Consider the bubble-chamber expansion curve (Fig. 1), plotting as abscissa the time and as ordinate the pressure in the chamber. In the usual mode of operation several particles enter the chamber at a moment corresponding approximately to the minimum pressure in the expansion curve, and several milliseconds after the passage of the particles a light flash is provided (time t_1). If the time of passage of the particles is shifted to the left of the minimum, then at some t_0 it is possible to reach a region of pressure when conditions for bubble formation do not exist (the pressure is too high). At time t_0 a very large number of primary particles can be admitted to the chamber, which activate the chamber material and the target in it. At the same time the decay of the activated nuclei begins, but the decay electrons are not yet visible. As the pressure is reduced, the conditions in the chamber approach those necessary for bubble formation, and starting at time t_2 the decay electrons can be seen reliably. The time $t_2 - t_0$ is the dead time of the apparatus for detection of decays. Thus, in the chamber it is possible to record all decays which occur during the time from t_2 to some time t_3 (the interval $t_1 - t_3$ is the minimum time necessary for growth of bubbles to the size necessary for detection). Since the time $t_2 - t_0$ is several milliseconds, then for a duration of the beam spill of the order of several tens of microseconds near t_0, all processes related to ordinary interactions can be completed and the chamber will record only delayed emissions of the nuclei.

EXPERIMENT WITH THE LYUDMILA CHAMBER

The two-meter hydrogen bubble chamber Lyudmila at the High Energy Laboratory of our Institute was bombarded by 12.2-GeV/c π^- mesons. The π^--meson flux was 10^5 particles per cycle. A target of tantalum ($Z = 73, A = 180.88, \rho = 16.6$ g/cm^3) of length 0.3 cm along the beam was placed in the chamber. Analysis of photographs made at various moments of time shows that the dead time $t_2 - t_0$ is 5 msec, the time for detection of decays is $t_3 - t_2 = 4$ msec, and the time $t_1 - t_3$ is 2 msec.

In 1600 frames we recorded 573 decay electrons or positrons from the target, and in 550 frames we found 77 decay electrons or positrons in the hydrogen of the chamber. The energy spectra of the particles are shown in Fig. 2 (the energy was determined on the basis of the range): Fig. 2a shows the spectrum of electrons or positrons from the target, emitted in the beam direction (240 events); Fig. 2b shows the spectrum of such particles emitted opposite to the beam (333 events); Fig. 2c is the difference between these two spectra, and Fig. 2d is the spectrum of electrons from the hydrogen of the

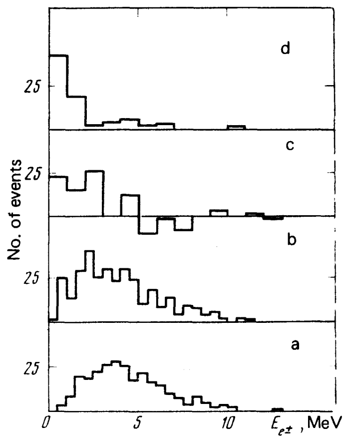

FIG. 2. Spectrum of decay electrons or positrons in the Lyudmila chamber: a—decay particles from the target along the beam; b—decay particles from the target opposite to the beam; c—the difference of spectra a and b; d—spectrum of particles in the hydrogen of the chamber.

chamber (15 events along the beam and 65 opposite to the beam). The spectra c and d are not greatly different from each other. Apparently the difference in the spectra of particles from the target emitted opposite to the beam and along it, and also the same difference for the particles from the hydrogen of the chamber, arise as the result of Compton scattering of delayed γ rays from decay of excited nuclei of the rear wall of the chamber, where the beam hits. We note that the distances of the target from the front and rear walls of the chamber are in the ratio 2 : 1. The main spectrum of particles from the target arises from decay of excited fragments produced in interaction of π^- mesons with tantalum nuclei.

However, the properties of the spectra presented are not the subject of our investigation. The number of observed particles from ordinary decays with energy ≤ 16.4 MeV is necessary only for estimation of the permissible chamber loading at which a photograph can still be processed.

To estimate the non-beam background (from cosmic rays) we took 600 photographs without the beam. In these photographs we did not find a single track leaving the target.

In the experiment we did not find a single decay with $E_{e\pm} > 16.4$ MeV. The upper limit of the cross section for production of a superdense nucleus under the present experimental conditions which would decay with a lifetime τ_c is estimated for the tantalum target (if one decay event were observed) from the formula

$$\sigma_{\text{upper}} = 0{,}6 \cdot 10^{-22} / W_c N_0, \qquad (1)$$

where $N_0 = n_0 k$ is the total flux of primary particles, n_0 is the flux in one cycle, k is the number of frames, and

$$W_c = \exp\left(-\frac{t_2 - t_0}{\tau_c}\right) - \exp\left(-\frac{t_3 - t_0}{\tau_c}\right) \qquad (2)$$

is the probability of observing a decay having a lifetime τ_c. In our case $N_0 = 10^5 \times 1.6 \times 10^3 = 1.6 \times 10^8$ particles. Then we have

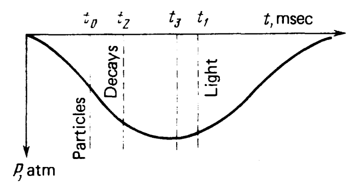

FIG. 1. Time diagram showing the expansion curve.

$$\sigma_{\text{upper}}=3.7\cdot 10^{-31}/W_c. \quad (3)$$

In Table I we have given the probabilities of observation and the upper limits of the cross sections for production of a superdense nucleus obtained in the present experiment. The experiment described is preliminary, and therefore we do not give the accuracy in determination of the cross sections.

Analysis of the data obtained permits the conclusion that by turning on the chamber magnetic field, which will significantly improve the conditions of observation, it will be possible to increase the primary flux to 10^8 particles per cycle. With this flux in 2×10^5 photographs it is possible to determine cross sections at the level 10^{-33}–10^{-35} cm^2/nucleus in the lifetime range indicated. The best estimate of the cross section so far obtained by Pontecorvo and his co-workers by electronic methods, for $\tau_c=5$ msec, is 8×10^{-34} cm^2 in the Pb nucleus.[3]

EXPERIMENT WITH THE TWO-METER PROPANE CHAMBER

The TPK-500 chamber was bombarded by 5-GeV/c protons in the proton synchrotron at the High Energy Laboratory. Three tantalum targets each of length ≈ 0.1 cm along the beam were placed in the chamber. As a result of the high density of propane, the primary beam undergoes strong scattering and the secondary particles can hit the sidewalls of the chamber of the chamber, producing in them delayed γ rays. The primary beam was rather broad in its transverse dimensions and could hit the flange of the front chamber wall. In addition, in the carbon of the propane a number of processes occur which lead to excitation and subsequent decay of carbon nuclei or its fragments with emission of electrons and γ rays. Therefore in this experiment the background contaminating a frame was ~30 times greater than in the Lyudmila chamber.

Matters are significantly improved on turning on the magnetic field of the chamber, when a large fraction of the tracks from low-energy electrons are seen as points. In addition, at the present time it has been possible to obtain a primary beam of significantly smaller size, which also improves the background conditions.

Analysis of photographs taken at various moments of time gives the following values: dead time $t_2-t_0=8$ msec, decay detection time $t_3-t_2=5$ msec, $t_3-t_1=5.5$ msec.

In Fig. 3 we have shown the spectra of observed electrons, pairs from γ rays, and positrons. The crosshatched distributions are events from the region of the beam. The energy distributions of the pairs and the electrons are identical outside and inside the beam region. In the electron spectrum two peaks are visible, one of which coincides with the peak observed for pairs from γ rays and is apparently an effect from asymmetric pairs from the same γ rays, and the other, located at lower energies ($E_{e^-}\approx 2.5$ MeV), is due to decay of excited carbon nuclei and their fragments. The spectrum of positrons outside the beam is similar to the distribution for electrons near the high-energy peak, and owes its origin to the effect from asymmetric pairs.

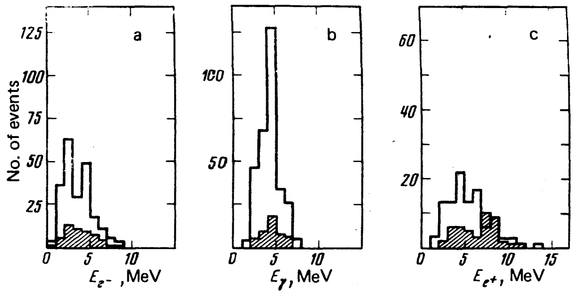

FIG. 3. Spectra of delayed particles in the propane chamber: a—electrons; b—γ rays; c—positrons. The distributions for particles in the primary-beam region have been crosshatched.

In the spectrum of positrons from the beam region, two peaks are visible: one at $E_{e^+}=4.5$ MeV from asymmetric pairs, and the other at $E_{e^+}=8$ MeV which has a bell shape. This second peak arises from the decay of the radioactive nitrogen nucleus N_7^{12} from the reaction $C_6^{12}(p,n)N_7^{12}$, which occurs with a cross section 0.035×10^{-27} cm^2 (Ref. 4). The maximum energy of the positrons in this decay is 16.4 MeV, and the spectrum has a bell shape with a maximum at 8.2 MeV; the half-life of N_7^{12} is about 11 msec.[5] Detection of this decay in the chamber permits determination of the primary-beam intensity. From 27 cases of N_7^{12} decay found in 2000 frames, the photon flux is estimated as $(8\pm2)\times10^3$ particles per cycle.

In 2000 frames we found no decays with energy >16.4 MeV either in the target or in the propane (the events in propane were selected in a length of 35 cm).

The results of determination of the upper limit of the cross section for production of a superdense nucleus with lifetime τ_c are given in Table II.

Analysis of the background conditions permits us to conclude that the primary flux can be increased up to 10^6 particles per cycle. Then in 2×10^5 frames it is possible to determine cross sections at the level 10^{-3}–10^{-34} cm^2/nucleus. In this case to determine the background from cosmic rays, in the case of observa-

TABLE I.

τ_c, msec	W_c	σ_{upper}, 10^{-29} cm2 (per Ta nucleus)	τ_c, msec	W_c	σ_{upper}, 10^{-29} cm2 (per Ta nucleus)
0.5	$4.4\cdot10^{-5}$	830	50	$6.3\cdot10^{-2}$	0.60
1	$6.7\cdot10^{-3}$	5.7	100	$4\cdot10^{-2}$	0.95
5	$2\cdot10^{-1}$	0.19	1000	$4\cdot10^{-3}$	9.5
10	$2\cdot10^{-1}$	0.19			

TABLE II.

τ_c, msec	W_c	σ_{upper}, 10^{-29} cm2 (per Ta nucleus)	σ_{upper}, 10^{-29} cm2 (per C nucleus)
0.5	10^{-7}	$3.8\cdot10^6$	$1\cdot10^5$
1	$3.3\cdot10^{-4}$	1100	31.0
5	$1.3\cdot10^{-1}$	2.9	0.077
10	$1.8\cdot10^{-1}$	2.1	0.056
50	$8\cdot10^{-2}$	4.8	0.13
100	$5\cdot10^{-2}$	7.6	0.2
1000	$5\cdot10^{-3}$	76	2

tion of a decay particle with the expected characteristics, it is necessary in principle to take at least 2×10^5 photographs without the accelerator beam, since the *a priori* estimate of the background from cosmic rays depends strongly on the details of location of the apparatus, which makes such an estimate practically impossible.

An advantage of experiments in the proton synchrotron at the High Energy Laboratory is the possibility of bombarding the chamber by heavy nuclei with an easily controlled energy. It is possible that an increase of density is easier to achieve if the target is bombarded by heavy nuclei.

An advance to shorter lifetimes is possible by construction of bubble chambers with a steeper rise of the expansion curve.

In principle it is possible to use streamer chambers and single crystals of AgCl, which may permit searches for decays of superdense nuclei to be accomplished over a wide range of lifetime.

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Temperature breaking of hydrogen bonds in water on negative-pion capture by hydrogen

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The probability W for capture of π^- mesons by hydrogen in water has been measured in the temperature range from -120 to $+440$°C. It is shown experimentally that in the transition from 0°C to the critical state the probability W rises by 100%, while at temperatures below zero and above the critical temperature up to 440°C, $W=$ const. The data show that on formation of hydrogen bonds in water the electron density in the hydrogen atom decreases. These results are in good agreement with the model of breaking of hydrogen bonds in water on heating proposed by Haggis, Hasted, and Buchanan [J. Chem. Phys. **20**, 1452 (1952)].

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One of the most important properties of water is its capacity for formation of hydrogen bonds. The great interest in this type of chemical interaction is explained by its major role in physical, chemical, and particularly biological processes. Modern ideas regarding the nature of the hydrogen bond permit it to be discussed as a bond of the donor-acceptor type.[1]

The best studied system with hydrogen bonds is water.[2] It occupies one of the first places in the series of compounds in which the hydrogen bond is manifested most strongly.[2] For example, it is the existence of hydrogen bonds which explains the strange dependence of the density of water on temperature: at $p=1$ atm the density of ice is less than the density of water, the density of water having a maximum at 4 °C. It is considered that hydrogen bonds O–H...O in water are broken on heating. According to the model of Bernal and Fowler,[3] and according to the data of x-ray structure analysis (see Ref. 2, page 311) and the work of Tödheide (Ref. 2, p. 463) water, when heated above 200 °C, loses the properties of an associated liquid. However, according to newer ideas, hydrogen bonds in water exist, although in a decreasing fraction of cases, up to the critical temperature 374.15 °C. In 1952 Haggis, Hasted, and Buchanan[4] (see also Ref. 2, p. 255) proposed a model of the temperature breaking of hydrogen bonds in water, by means of which it has been possible to explain the dependence of the static dielectric constant ε_s and the heat of evaporation L on temperature. According to this model, in ice there exist all possible hydrogen

