Search for decays of superdense nuclei in the two-meter propane chamber

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Upper limits have been determined for the cross sections for production of superdense nuclei at the level $5\cdot10^{-33}$–10^{-28} cm^2 in bombardment of targets of Ni, Pb, Cu, Ta, and C by protons with momenta 1.90, 3.36, and 9.86 GeV/c, α particles with momentum 0.95 GeV/c per nucleon, and carbon nuclei with momentum 3.36 GeV/c per nucleon. Decay particles with energy greater than 16.4 MeV were looked for in the two-meter propane chamber at the High Energy Laboratory, Joint Institute for Nuclear Research.

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Proceeding from the ideas of A. B. Migdal,[1] we have carried out a search for unusual decays which might occur as the result of the formation of superdense nuclei. For this purpose the two-meter propane bubble chamber of the High Energy Laboratory, Joint Institute for Nuclear Research, was bombarded by fluxes of protons, α particles, and carbon nuclei. Targets of Ta (0.2 cm), Pb (1 and 0.6 cm), Ni (0.6 cm), and Cu (0.6 cm) were placed in the chamber.

The essence of the method has been described in our previous paper.[2] The primary particles enter the chamber at the time when the pressure in it is so high that conditions for bubble formation no longer exist. The particle activate the target and the working liquid of the chamber. After a certain time of the order of several milliseconds, which we shall call the dead time, when the chamber pressure drops sufficiently that conditions exist for formation of an easily visible track, recording of decays begins; the interval of observation time for decays is defined as from the end of the dead time to the light flash (in practice it is somewhat smaller, since it was necessary to allow time for growth of the bubbles to the necessary size).

Under these conditions in the chamber it is possible to disregard the large fluxes of particles (up to 10^6–10^7 particles per cycle under our experimental conditions). This provides the possibility of studying processes occurring with cross sections of the order 10^{-33}–10^{-34} cm^2. The only physical background is the background from cosmic rays, which can produce energetic γ rays which in turn produce high-energy electrons and positrons in the targets and in the propane as the result of Compton scattering and pair production. However, this background is easily evaluated in the chamber, although it requires a large amount of work in scanning.

TABLE I.

Type of incident nucleus	p	p	p	α	$_6C^{12}$
Momentum of incident nucleus, GeV/c per nucleon	1.90	3.36	9.86	0.95	3.36
Type of target nucleus	Ni, Pb, Cu, C	Pb, C	Ta, C	Ni, Pb, Cu, C	Ni, Pb, Cu, C
Total particle flux	$6.6\cdot10^6$	$1,3\cdot10^9$	$2.4\cdot10^8$	$6.9\cdot10^6$	$1.1\cdot10^6$
Number of frames	4370	64000	5200	4350	2500

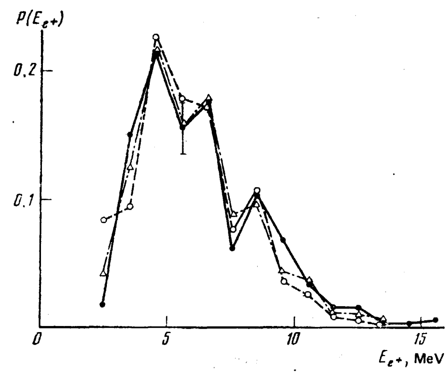

FIG. 1. Spectrum of positrons in relative units in the propane chamber for proton bombardments at the following momenta in GeV/c: ● $-P_p$ = 1.9, ○$-P_p$ = 3.36, △$-P_p$ = 9.86.

In Table I we have listed the characteristics of the experiments. The target is the carbon $_6C^{12}$ contained in 52 cm of propane. While the bombardments by 1.9-GeV/c protons and by α particles in carbon nuclei the flux of particles into the chamber in a cycle was of the order 10^2–10^3 and was reliably measured by the scintillation counters located in front of the chamber, on the other hand in the bombardments by protons with momenta 3.36 and 9.86 GeV/c the particle fluxes were of the order 10^5, and with a spill duration ≈1 msec counts were missed in the electronics. Therefore the evaluation of the flux in the last two cases was carried out on the basis of the number of observed e^+ from decays of radioactive nitrogen $_7N^{12}$. The cross section for production of this nucleus in the reaction $p + {}_6C^{12} \to {}_7N^{12}$ was

TABLE II.

		P_p=1.90 GeV/c			
τ_s, msec	W_s	σ_{upper}			
		10^{-30} cm^2 (per C nucleus)	10^{-29} cm^2 (per Ni nucleus)	10^{-29} cm^2 (per Cu nucleus)	10^{-29} cm^2 (per Pb nucleus)
2	$2.5\cdot10^{-3}$	80.5	109.0	175.0	391.0
5	$8.6\cdot10^{-2}$	2.3	3.1	5.0	11.2
10	$2.3\cdot10^{-1}$	0.9	1.2	1.9	4.1
50	$2\cdot10^{-1}$	1.0	1.3	2.1	4.8
100	$1.2\cdot10^{-1}$	1.6	2.2	3.5	7.8
1000	$1.5\cdot10^{-2}$	13.3	18.0	29.0	64.6

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TABLE III.

τ_s, msec	W_s	σ_{upper} 10^{-33} cm² (per C nucleus)	σ_{upper} 10^{-31} cm² (per Pb nucleus)
		$P_p = 3.36$ GeV/c	
2	$1.5\cdot10^{-3}$	694.0	201.0
5	$6.9\cdot10^{-2}$	16.0	4.4
10	$2\cdot10^{-1}$	5.3	1.5
50	$1.8\cdot10^{-1}$	5.9	1.7
100	$1.1\cdot10^{-1}$	9.7	2.8
1000	$1.3\cdot10^{-2}$	82.2	24.0

estimated with use of the data of Lindstrom *et al.*,[3] where it was determined for two values of the primary energy. Since this reaction apparently occurs through π-meson exchange, its cross section should fall off with energy in proportion to some inverse power of the momentum of the incident particle. A fit to the data of Ref. 3 gives for the $p+{}_6C^{12}\to{}_7N^{12}$ cross section a value $\sigma(P)=0.086\cdot(P)^{-0.87}$ mb, where P is the momentum in GeV/c.

In the figure we have shown in relative units the spectra of decay positrons in the chamber in the region of the primary proton beam for various incident-particle momenta. The similarity of the spectra is evident. The peak at a positron energy from 8 to 9 MeV is due to the decay of ${}_7N^{12}$ (the maximum e^+ energy in this peak is 16.4 MeV). However, the positron decays of other nuclei such as ${}_5B^8$ contribute in the positron energy region ≥ 8 MeV (for ${}_5B^8$ the maximum decay energy is 14 MeV). If we assume that the contribution from decays of all other nuclei except ${}_7N^{12}$ to the region ≥ 8 MeV amounts to half of all observed positrons, then the flux of primary protons determined from the number of observed positrons from ${}_7N^{12}$ with use of the cross section for production of ${}_7N^{12}$ agrees with the flux measured by the counters for an incident-proton momentum 1.9 GeV/c. Then, assuming similarity of the positron spectra for protons with momenta 1.9, 3.36, and 9.86 GeV/c, we can estimate the proton fluxes in the experiments at $P_p=3.36$ and 9.86 GeV, assuming that in the spectra of positrons with $E_{e^+}\geq 8$ MeV the decay of ${}_7N^{12}$ is responsible for half of the events. The flux values determined in this way for primary protons with momenta 3.36 and 9.86 GeV/c are given in Table I.

In all of the bombardments we found no event which could be uniquely interpreted as an unusual decay ($E_{decay} > 16.4$ MeV). Thus, we are determining only upper limits for formation of superdense nuclei and their subsequent decay.

TABLE IV.

τ_s, msec	W_s	σ_{upper} 10^{-32} cm² (per C nucleus)	σ_{upper} 10^{-32} cm² (per Ta nucleus)
		$P_p = 9.86$ GeV/c	
2	$2.0\cdot10^{-4}$	2720.0	2310.0
5	$3.1\cdot10^{-2}$	17.6	14.9
10	$1.3\cdot10^{-1}$	4.2	3.6
50	$1.5\cdot10^{-1}$	3.6	3.0
100	$9.5\cdot10^{-2}$	5.7	4.8
1000	$1.2\cdot10^{-2}$	46.0	39.2

TABLE V.

τ_s, msec	W_s	σ_{upper} 10^{-30} cm² (per C nucleus)	σ_{upper} 10^{-29} cm² (per Ni nucleus)	σ_{upper} 10^{-29} cm² (per Pb nucleus)	σ_{upper} 10^{-29} cm² (per Cu nucleus)
		$P_\alpha = 0.95$ GeV/c per nucleon			
2	$2.5\cdot10^{-3}$	138.0	107.0	565.0	245.0
5	$8.6\cdot10^{-2}$	4.0	3.1	16.2	9.6
10	$2.3\cdot10^{-1}$	1.5	1.1	6.0	3.5
50	$2.0\cdot10^{-1}$	1.7	1.3	6.9	4.0
100	$1.2\cdot10^{-1}$	2.8	2.1	11.3	6.7
1000	$1.5\cdot10^{-2}$	23.0	17.9	95.0	56.1

TABLE VI.

τ_s, sec	W_s	σ_{upper} 10^{-29} cm² (per Ni nucleus)	σ_{upper} 10^{-28} cm² (per Pb nucleus)	σ_{upper} 10^{-28} cm² (per Cu nucleus)	σ_{upper} 10^{-29} cm² (per C nucleus)
		$P_C = 3.36$ GeV/c per nucleon			
2	$7.5\cdot10^{-3}$	219.0	154.0	109.0	63.9
5	$1.0\cdot10^{-1}$	15.9	11.2	7.9	4.7
10	$1.8\cdot10^{-1}$	9.3	6.5	4.6	2.7
50	$9.8\cdot10^{-2}$	16.8	11.8	8.4	4.9
100	$5.5\cdot10^{-2}$	29.6	20.8	14.7	8.7
1000	$6.2\cdot10^{-3}$	264.0	185.0	131.0	77.0

The accuracy of calculations of the cross sections is determined by the time width of the beam (≈1 msec) in the cases of the accurate measurement of the flux and varies inversely in proportion to the lifetime of the superdense nucleus. For a lifetime 2 msec the accuracy is ~50%. For experiments in which the flux is determined from the number of ${}_7N^{12}$ decays, the accuracy is determined in addition by the statistics of the observed decays and by the reliability of extrapolation of the cross section for the $p+{}_6C^{12}\to{}_7N^{12}$ reaction, which is hard to estimate as the result of the scarcity of data in the literature.

In Tables II–VI we have given values of the upper limits of the cross sections σ_{upper} for production of superdense nuclei in various processes for several values of their lifetime τ_s for various primary-particle energies. In calculation of the cross sections we took into account the attenuation of the particle flux in passing through the chamber and target, with use of the inelastic interaction cross sections of protons, α particles, and carbon nuclei at the corresponding energies,[4] The probabilities W_s of observing the decays were calculated as in Ref. 2. The dead times in the experiments varied from 9.7 to 17 msec.

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