Spontaneous transitions of nuclei to a superdense state

V. I. Aleshin, A. Ya. Balysh, V. M. Galitskiĭ, Yu. V. Kozlov,
V. I. Lebedev, V. P. Martem'yanov, L. A. Mikaélyan,
A. A. Pomanskiĭ,(1) and V. G. Tarasenkov

I. V. Kurchatov Institute of Atomic Energy

(Submitted June 18, 1976)
Pis'ma Zh. Eksp. Teor. Fiz. **24**, No. 2, 114–117 (20 July 1976)

We report the results of an experimental search for spontaneous transitions of certain nuclei from the ordinary to the superdense state. We discuss the mechanisms of these transitions. Limits of the superdense-state parameters are obtained.

PACS numbers: 21.65.+f

Migdal's analysis [1] of the pion field in nuclear matter shows that one of the excitation modes of this field may be unstable. This phenomenon, usually called π condensation, occurs at nucleon densites n that exceed a certain critical density n_c and possibly leads to the appearance of a second minimum on the plot of the nuclear energy ϵ per isotope against the density of the isotope. Of greatest interest for further discussion is the case of the existence of stable superdense nuclei with density n_s (the possibility of the existence of such nuclei was considered for another reason by Lee and Wick. [2] In this case ordinary nuclei are metastable and can go over spontaneously to the superdense state.

The reason why ordinary nuclei are in the metastable state and not in the more favored superdense state may be that the process of formation of medium and heavy nuclei from the lightest nuclei has proceeded via a consecutive capture reaction, and that for the lightest nuclei the superdense state has low

TABLE I.

Nucleus	C	F	Na	I	W
τ , years	10^{22}	10^{22}	$3\cdot 10^{20}$	$3\cdot 10^{20}$	10^{21}

probability, since the critical density increases with decreasing atomic weight.[3]

The foregoing arguments have stimulated a search for spontaneous transitions of nuclei to the superdense state. In an experiment performed in the Neutrino Station of the USSR academy of Sciences at a depth of 600 m w.e., two scintillation setups were used, one containing 25 kg of sodium iodide, and the other 3 kg of scintillating fluorobenzene C_6F_6.

To decrease the external background, a shield of tungsten and anti-coincidence systems were used. We registered in the experiment γ quanta with energies in the range from 3 to 10 MeV. These quanta should be accompanied by a transition to the superdense state, if the energy $\Delta\epsilon$ released thereby exceeds 0.05—1 MeV/nucleon for the investigated nuclei.

We did not observe in the experiment any effect connected with transitions to the superdense state. The measured counting rate, due apparently to cosmic rays and radioactive contamination of the material, was 0.1 events per kilogram and per day in the setup with fluorobenzene, and two event per kilogram per day in the setup with the sodium iodide. The counting rates with allowance for the registration efficiency and the geometry lead to the lower bounds of the lifetimes τ of the nuclei as seen in Table I.

These values enable us to estimate the lower bounds of the density n_s and of the energy barrier separating the ordinary state from the superdense state. A plot of the nuclear energy per nucleon, corresponding to the existence of stable superdense nuclei, is shown in the figure.

This curve can be approximated by the expression

$$\epsilon = \epsilon_0 + \frac{k}{2}\left(\frac{n-n_0}{n_0}\right)^2 + \frac{q}{6}\left(\frac{n-n_0}{n_0}\right)^3 - \frac{a}{2}\left(\frac{n-n_c}{n_0}\right)^2 \theta\,(n-n_c), \tag{1}$$

in which k is a known quantity connected with the compressibility of the nuclear matter and equal to $k \cong 32$ MeV,$^{2)}$ while the coefficients q and α and the values of n_c are varied parameters. The last term corresponds to the energy gain in the appearance of the π condensate at $n > n_c$.

The probability of the transition to the superdense state can be obtained from the usual picture of the below-barrier transition

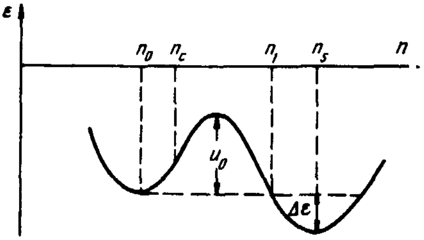

FIG. 1.

TABLE II.

	Na^{23}	I^{127}	W^{184}
n_c/n_0	3.4	1.3	1.2
n_s/n_0	9 8	3.0	2.5
U_0, MeV/nucleon	314	5.4	2.6

$$1/\tau = \omega \exp\left\{-\frac{2}{\hbar}\int_{r_0}^{r_1} dr\sqrt{2M_{\rm eff}\;(U-E)}\right\}, \tag{2}$$

where ω is the frequency of the attempts, and is equal in order of magnitude to the ratio of the speed of sound to the nuclear dimension, yielding $\omega \approx 10^{21}$ sec^{-1}, while r_0 and r_1 are the radii corresponding to the densities n_0 and n_1; $M_{\rm eff}$ is the effective mass and equals 3/5 of the nuclear mass in the case of homogeneous compression. It is necessary to change over in (2) to quantities per nucleon, i.e., $U-E=A(\epsilon-\epsilon_0)$. The argument of the exponential in (2) depends, generally speaking, on the energy $\Delta\epsilon$ per nucleon released in the transition, but at not too large $\Delta\epsilon$ this dependence is weak and in the subsequent estimates we obtain $\Delta\epsilon=0$. As a result, the formula for the transition probability becomes

$$1/\tau = \omega \exp\left\{-\,\mathrm{const}\; F\left(\frac{q}{k}, \frac{n_s}{n_0}\right)A^{4/3}\right\}. \tag{3}$$

Equating τ to the experimental lifetime, we obtain the lower bound of n_c/n_0. This quantity turns out to be a smooth function of the ratio q/k (in the q/k interval from 0.5 to 2.0). Approximate values of n_c/n_0 and the corresponding values of n_s/n_0 and U_0 are listed in Table II.

It is seen from the table that with decreasing atomic number the lower bound of n_c/n_0 and the height of the barrier per nucleon increase. Fluorine and carbon are not included in the table; the critical densities and barriers for them turn out to be even higher, but the concepts developed here may be doubtful for such light nuclei. A more detailed analysis of the results and of the limitations imposed on the expansion coefficients in (1) will be carried out subsequently.

[1] Nuclear-Research Institute.

[2] We note that a quantity nine times larger is introduced in a number of studies devoted to the properties of nuclear matter.

---

[1] A. B. Migdal, Zh. Eksp. Teor. Fiz. **61**, 2209 (1971) [Sov. Phys. JETP **34**, 1184 (1972)]; A. B. Migdal, O. A. Markin, and I. N. Mishustin, Zh. Eksp. Teor. Fiz. **66**, 443 (1974) [Sov. Phys. JETP **39**, 212 (1974)].

[2] T. D. Lee and G. C. Wick, Phys. Rev. **D9**, 2291 (1974).

[3] É. E. Sapershteĭn, S. V. Tolokonnikov, and S. A. Fayans, Preprint IAE No. 2571, 1975.