Quantum entanglement, a form of nonclassical correlation, has been an important issue in recent debates on the foundations of quantum mechanics. In quantum information science, the entanglement is considered as a physical resource, which plays a crucial role in quantum teleportation, 2 and quantum key distribution, 3, 4 and measurement. 11 In such applications, possible gain from using the cat states is proportional to the number of particles which can be entangled. In this letter, we describe an experiment focused on creating a pseudopure cat state of a system of 12 dipolar-coupled nuclear spins. At present, it is the largest and the most complex composite quantum system where manipulations with individual states present, it is the largest and the most complex composite quantum system of 12 dipolar-coupled nuclear spins. At time τ=65.6 μs corresponds to a rotation, caused by the heteronuclear dipolar couplings, of the protons’ six-quantum (6Q) coherence by π when the 13C spins are in the state (A) or (B). The 1H linear-response spectrum of (A) is presented in Fig. 2(a). Due to the high symmetry of the benzene molecule, the spectrum of (A) has only one 1H peak and one 13C peak (not shown). Thermal equilibrium 1H and 13C spectra of this system have thousands of unresolved peaks. Starting from (A), one can obtain other pseudopure states by using nonselective “hard” and selective “soft” pulses. 13 As an example, 180° hard pulses on both protons and carbons convert the state (A) into the pseudopure state (B) [Fig. 2(b)].

To create the twelve-spin cat state, we expanded the scheme used to build the seven-spin cat state in benzene with

FIG. 1. Experimental pulse sequence. For 1H and 13C channels, rectangular shapes represent 90° hard and sinc-shaped pulses, respectively. The symbols x, y, z, and y over the pulses represent relative phases or the directions of the pulses in the rotating frame. Pulsed gradient channels G, G, and G provide linear gradients of static magnetic field along the x, y, and z axes, respectively. (Step A) preparation of the pseudopure state; (Steps B–E) creation of the 12-spin cat state; (Steps F–J) state verification and lifetime estimation.

**Twelve-spin “Schrödinger cat”**

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Pseudopure “cat” state, a superposition of quantum states with all spins up and all spins down, is experimentally demonstrated for a system of 12 dipolar-coupled nuclear spins of fully 13C-labeled benzene molecule oriented in a liquid-crystalline matrix. © 2005 American Institute of Physics.

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Therefore, with optimized parameters, the 16-pulse sequence, which is not directly observable. The pulse sequence and their phases were arranged so that Steps G, H, I, and J are, respectively, the inverses of the Steps B–E. The pulse sequence of a 16-pulse sequence were applied to convert the six carbon spins, and some modification of the pulse sequences and their phases were arranged so that Steps G, H, I, and J are, respectively, the inverses of the Steps B–E. The pulse sequence produces a superposition of the states \(|u_c|u_h\) and \(|d_c|d_H\) rather than their mixture. The peak marked by an asterisk in Figs. 2(c) and 2(d) comes from an impurity, which gives very high signal peaks in the thermal equilibrium spectrum.

It was difficult to accurately measure the cat state decoherence time. There are several reasons for that. The pulse sequence is very long: There are 1301 radio-frequency and gradient pulses in the total sequence. Therefore, despite considerable efforts to tune its parameters, accumulation of errors was unavoidable. The results of these accumulated errors and relaxation are the decreased signal intensity and some unwanted peaks in the center on the spectrum in Fig. 2(d). Measurements were performed near the sensitivity limit, and instabilities of the spectrometer during long acquisition times affected the accuracy. Due to weaker carbon-carbon interactions, the multiple-quantum carbon subcomponents in the state \(|\Psi_F\rangle\). All of our measurements gave unexpectedly short lifetime of 3.2 to 4.7 ms. We are not absolutely sure that it is a true lifetime of the cat state but, at the same time, we cannot suggest any explanations of how any of the nonidealities mentioned above could cause such a short decay time.

For comparison, we present below some accurately measured relaxation times for this and similar systems. The decay time for the diagonal elements of the cat state, measured with varying delays in Step F but without the time-reversed sequences of Steps G–J, was found to be 0.30 s. Conventionally measured \(T_1\) and \(T_2\) relaxation times are 1.7 s and 0.25 s for \(^1\text{H}\) and 2.5 s and 0.26 s for \(^13\text{C}\), respectively. The decay time of protons’ 6Q coherence was measured when the 6Q coherence was excited starting with one of the two different initial conditions: The thermal equilibrium state and the pseudopure ground state. The thermal equilibrium initial state, we averaged the decay times for different peaks. The decay times were 70 ms and 16 ms for the thermal equilibrium and pseudopure initial states, respectively. This difference is a general feature of relaxation in composite systems: The (pseudo) pure state relaxes, the intensity only leaves the state; for relaxation of the same state in a mixture, intensities of coherences or populations of levels are transferred in both directions.

In similar systems of natural-abundance benzene (six spins) and single-labeled benzene (seven spins) in the liquid-crystalline matrix, the relaxation times are the following. For a six-spin system of natural-abundance benzene, average \(T_1\), \(T_{1p}\), \(T_2\), and the decay time of the pseudopure ground state (all spins up) and 6Q coherence are 3.30 s, 1.75 s, 0.47 s, 0.75 s, and 0.087 s, respectively. For a seven-spin system of single-labeled benzene, \(T_1\) and \(T_2\) of individual peaks are 1.7–2.3 s and 0.1–0.7 s for proton spins and 1.4–2.9 s and 0.1–0.7 s for carbon spins.
0.3–1.1 s for carbon spins, respectively. The decay time of the protons’ 6Q coherence, excited from the thermal equilibrium state, relaxation times of the diagonal and off-diagonal elements of the seven-spin cat state are 0.073 s, 0.49 s, and 0.029 s, respectively.

In summary, a 12-spin cat state has been experimentally demonstrated in a system of dipolar-coupled nuclear spins of fully 13C-labeled benzene in a liquid-crystalline matrix. In terms of the number of qubits, it is the largest “Schrödinger cat” ever built.