APPLICATION OF MULTIPLE QUANTUM RESONANCES TO THE STUDY OF THE LIQUID STRUCTURE

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Physical properties and structure of liquids, in particular, sea and fresh water are studied based on the nuclear magnetic resonance and the laser and ultrasonic methods of pulsed coherent spectroscopy. The dependence of the quantum relaxation parameters of liquid molecules on the concentration of various inorganic admixtures and living microorganisms (bacteria) is revealed.

Liquids, especially water, are the systems of strongly interacted particles whose physical properties are only poorly known.

In this paper we try to apply simultaneously three developed methods of quantum physics. They are the nuclear magnetic resonance (NMR) pulsed spectroscopy, the laser pulsed spectroscopy, and the coherent ultrasonic spectroscopy harnessing stimulation of resonance transitions and change of the liquid state upon exposure to high–power coherent radiation. Each of the above–enumerated radiation fields has its own advantages and disadvantages. Sound interacts with substance most strongly, that is why it is more informative; however, it rapidly attenuates in liquid resulting in a loss of information and escape of important physical details.

The interaction of the dynamic and quasimagnetic (Fermi) molecular fields in liquids with electromagnetic multipoles of molecules or atoms as well as with electron and nuclear spins is of special interest. The spin degrees of freedom are internal for elementary particles and for this reason interact selectively with the molecular fields of liquid. As mentioned above, these fine effects erase due to dissipation of the acoustic energy, and special methods must be implemented capable of instantaneous retrieval of this piece of information from the acoustic field *prior to* its erasing from the "acoustic memory."

To do this, we have used the NMR proton echo and laser excitation. The roles of laser photons in the measurement processes are twofold. On the one hand, they convert the information obtained from a nuclear spin into the optical frequency range thereby intensifying spin effects and facilitating their detection. On the other hand, the laser excitation of molecules translates them into excited states with larger multipole moments which create the stronger molecular fields. The central problem in the application of these methods is tuning to resonance with optical transitions by means of an available laser in the given liquid, especially in water. Away from resonance light pumping, as a rule, is insignificant. The spectra of optically active centers are well studied mainly in crystals and glass. As for liquids, they have not been used as working substance to develop new lasers. This explains the paucity of available experimental data. These factors make the experiments on treble resonance in liquids difficult. The main advantage of multiple resonances is the possibility of arising of nonlinear effects and interrelated phenomena in the dynamic pattern of the excited substance. These phenomena open up the new ways for solving the complicated problems of strongly interacting particles.

We have developed an experimental complex (see Fig. 1) intended for observation of the treble opto–acoustic radio–frequency NMR in the regime of spin induction and echo in compound media. We have studied the exposure of ultrasound to the organic molecules and compound liquids like blood and sea water. The experiments have been performed aimed at application of the acoustic NMR to medical and chemical diagnostics based on correlation of the bound states of water molecules in tissues, the acoustic Q–factors of organic resonators, the multipole–photon interaction, the times of longitudinal (T_1) and transverse (T_2 and T_2^*) relaxation of the multipole, and the intensity of echo–signal produced by nuclear spin.

The treble excitation method in combination with the analytic phase and energy relaxation makes it possible to use comprehensively and analyze the information about the dynamics of variable fields of acoustic deformation in liquids and amorphous organic media. Each component or each pair of the three variable components of the dynamic coherent field can be used for amplification or suppression of the other components, thereby improving the selectivity and increasing the sensitivity of the method. The radio–frequency part is capable of operating in the frequency range 3–10 MHz and recording the relaxation time in the interval $50 \cdot 10^{-6}$–10 s, the resolution time of the setup of 10^{-5} s, and the operating temperature ranging from the nitrogen temperature to 375 K accurate to 0.1 K. The error in determining the relaxation parameters is 0.5%. The software helps us to synthesize various pulse trains consisting of 2–4 pulses (the Karr–Parcel and the Meby–Hill pulse trains). The ultrasonic block is capable of creating the acoustic pumping field in the stationary regime in a volume of 0.5 cm^3 in the frequency range 0.5–15 MHz whose power varies in the range 30–250 W. The feasibility of observation of the polarization echo is provided by a capacitance pickup placed in the electric field. A pulsed Cu–vapor laser generating in the visible range at a wavelength of 0.5105 μm with the pulse repetition frequency 5–20 kHz is used for light pumping. The output radiation power is 5 W. The laser can generate radiation pulses every 5–15 ns with the power 40–60 kW.

The complex was tested for aqueous solutions of the paramagnetic salts, food bacterium solutions, and solutions containing different types of protein and fat as well as for polar ants and pelagic organisms. The acoustic power supplied to the nuclear magnetic resonator results in the change of the character of interaction of the radio–frequency field with the sample and the transformation of

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the dynamic structure of substance and relaxation processes taking place in it. The coherent molecular fields electromagnetic and nuclear in origin excited by ultrasound directly act upon the electron and nuclear spins in the sample. Resonance transitions of the elastic multipoles of molecules and ions are also possible upon exposure to acoustic pumping. The Fermi contact interaction, which is invariant under rotational transformations, is the most effective interaction. All the above–enumerated channels of acoustic actions enlarge the information content of the NMR method for investigation of liquids.

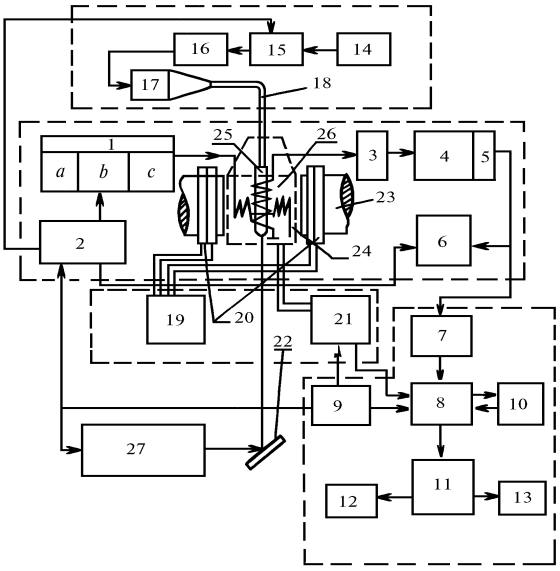

FIG. 1. Block–diagram of the model of the radio–opto–acoustic nuclear magnetic resonance. 1) Transmitter of coherent radio–frequency pulses: synthesizer of resonance frequencies (a), high–frequency gate and block of phase control over radio–frequency pulse (b), power amplifier (c); 2) block of selection of the operation programs; 3) preamplifier; 4) high–frequency amplifier; 5) synchronous detector; 6) memory oscillograph; 7) analog–digital converter; 8) commutator; 9) timer; 10) Mera–664 computer; 11) winchester; 12) X–Y recorder; 13) printer; 14)–18) block of acoustic pumping; 19) proton stabilizer of the magnetic field; 20) coils for the magnetic field correction; 21) thermostabilization system; 22) system of mirrors; 23) magnet; 24) nuclear magnetic resonance sensor; 25) sample; 26) thermostat; and, 27) pulsed laser.

The changes in the resonance frequencies of the NMR and relaxation time by about 10% were observed in our experiments. Higher harmonics of sound field in the frequency range 0.5–15 MHz were generated due to acoustic nonlinearity of the sample. They could be resonant with the proton spin. Various solutions of ions Cu^{2+}, I^{3+}, and Mn^{2+} were used. The optical pumping resulted in the excitation of the magnetic centers which changed their magnetic characteristics. This, in its turn, changed the time T_1 for the protons which interacted with paramagnetic centers.

The changes of the time T_1 on exposure to optical pumping were recorded for the following solutions: 1% solution of $CuSO_4 \cdot 5H_2O$ in water (from 21.64 to 23.08 ms), electrolyzed tap water with $pH = 4.2$ (from 1.8 to 1.94 s); water of the Black Sea (from 3.03 to 3.46, from 3.03 to 3.32, and from 2.88 to 3.10 ms), solution of the ions I^{3+} in water (from 3.61 to 4.18 ms), 5% solution of I in alcohol (from 0.69 to 0.81 s), and the same with addition of water (from 2.09 to 3.31 s). Acoustic pumping with laser excitation resulted in the spread of values of the time T_1. Addition of the organic molecules to water shortened the time T_1, and this effect intensified upon exposure to acoustic radiation. Shortening of the time T_1 is associated with adhesion of the water molecules to macromolecules resulting in lengthening of the correlation time of the interaction between proton and ion. Light pumping may change the conditions for adhesion of the molecules. We found that the parameter T_1 can be used to estimate the concentration of massive molecules in tissues and liquids.

The experiments with food bacteria in liquid showed that their vital activity changed the value of T_1 in surrounding liquid, and one could study the result of bacterial action on the liquid in the ultrasound field and the bacteria upon exposure to the acoustic field as well as to laser radiation by means of measuring T_1. The liquids with admixture of living organisms are essentially nonlinear systems with absolutely new dynamic properties. They open up fresh opportunities for the study of liquids on a higher technical level. It is also probable that the living organisms allow one to reach a higher sensitivity of the instrument intended for investigation of liquids. This follows from the fact that the nonlinearity of the system response to the external action becomes more pronounced as nonlinearity of the system strengthens and the system itself becomes more complicated. This finally results in the improved selectivity of the method of investigation of the liquid dynamics. In addition, one can study the self–organization mechanism in the living organisms from the dynamics of liquid. This mechanism is associated with the formation of strongly nonequilibrium states of substance at room temperature. These states can be obtained for inorganic substance only at helium or lower temperatures. For this reason, addition of living organisms to liquid may be considered as a factor decreasing its effective temperature by many orders of magnitude. Since the living system is not governed by thermodynamic laws, it may interact with its surroundings very strongly at any temperatures. Such properties of liquids have not been studied yet. Our investigations show that the cross radio–opto–acoustic excitation of the substance in living organisms and complicated systems is very promising for practical applications.