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1. Testing CPT theorem

Symmetry with regard to replacement of particles by antiparticles, mirror reflection, and time reversal is a fundamental theorem of quantum field theory. It has been confirmed for many processes, but in a system of charged leptons the precision of its testing remained rather low. This theorem is of particular interest for positronium atoms, because some anomalies have recently been observed in measuring the fine structure constant. P Moskal (Krakow University, Poland) and his co-authors have performed a new test of the CPT theorem in an experiment with orthopositronium [1]. Positrons were emitted by radioactive ^{22}Na and produced orthopositronium in porous silica. Orthopositronium annihilation to three photons was analyzed and angular correlations between the original orbital angular momentum of orthopositronium and the annihilation plane determined by photon pulses were examined (provided that CPT invariance is conserved, correlations are absent up to very small radiation corrections). Photons were recorded by a detector consisting of plastic scintillator bands. Its high time resolution allowed observing photon triples using the coincidence method. At the level of 10^{-4}, no CPT symmetry violation was found, which improves more than threefold the accuracy of the CPT theorem test for the orthopositronium system.

2. Nonequilibrium optical Bose–Einstein condensate

In their experiment, M Vretenar, C Toebes, and J Klaers (University of Twente, Netherlands) have examined the properties of Bose–Einstein condensate of photons under nonequilibrium conditions [2]. Quasi-two-dimensional room-temperature condensate was obtained in a water solution of dye between two mirrors 10 μm apart from each other. The photons could undergo absorption and reemission in the medium several times before leaving the system. Two optical arms of a Mach–Zehnder interferometer appeared in the condensate through nonuniform heating. This made it possible to investigate condensate coherence and characterize its properties depending on the absorbing properties of the medium. The photon condensate evolution has turned out to proceed with resistance to coherence-violating effects such as particle loss and destructive interference.

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3. Microscopic Fano laser

In 1985, A L Schawlow and C H Townes showed that laser coherence (radiation linewidth) is limited to the effect of quantum fluctuations and decreases upon lowering laser power and resonator Q-factor. The quantum fluctuation effect is particularly important for micro- and nanolasers because of a small number of photons in the resonator. A group of researchers from the Technical University of Denmark have developed a method [3] which makes it possible to heighten the coherence of micron-size lasers by using bound states in the continuum, formed by Fano interference, since these states suppress quantum fluctuations. The researchers created a microscopic laser-diode-pumped laser, which is a nanocavity with an active medium, coupled with a waveguide. Destructive Fano interference at the junction point gives almost ideal photon reflection. Such a 'Fano mirror' has already been demonstrated experimentally. The emission band of the new laser is more than 20 times narrower than that of other microscopic lasers. Microlasers can be applied in communication facilities, medical sensors, etc. For applications of powerful lasers, see [4].

4. Atomic optics

The study of atomic beam interference encounters the problem of electromagnetic atomic interaction leading to undesirable beam smearing and obstructing the cooling of atomic gases. Thermal velocities of atoms have been lowered to 50 pK to date, but in two directions of particle motion, while in all the three directions the gas could only be cooled to 350 pK. E M Rasel (Leibniz University Hannover, Germany) and his colleagues have developed a new approach to atomic optics using collective excitations in a degenerate gas in combination with magnetic lenses [5]. A cloud of Bose–Einstein condensate of ^{87}Rb atoms became prolate and left the trap, and quadrupole vibration modes were excited in it. The condensate evolution was observed by the absorption method for more than three seconds of free fall. When the magnetic lens focus shifted to infinity, the gas was cooled in three directions of atom motion to a record temperature of 38^{+6}_{-7} pK, the atom flux remaining well collimated. Extreme states of matter were the center of attention of V E Fortov and his colleagues [6]. Atomic interferometers are being applied in fundamental research and in gravimetry.

5. Photonic chip-based accelerator

The design of compact electron accelerators on chips several cm or mm in size is a new intensely developed area. Electrons are accelerated in them by laser pulses. Compact accelerators can be used, in particular, in radio therapy. The realization of such accelerators is difficult because of the necessity to control the electron beam propagation during its acceleration. R Shiloh (University of Erlangen-Nuremberg, Germany) and his co-authors have worked out and demonstrated the method of beam confinement in a narrow (225-nm) channel in a periodic silicon nanostructure 80 μm long [7]. In this structure, an electron-accelerating laser pulse was modulated, and the electron beam was focused using an alternating phase effect of radiation on electrons in different directions with minimal-loss electron transport, whereas, without a laser pulse, electrons were scattered quickly by the cavity walls. In the near future, such a method may allow electron beam acceleration up to MeV energies.

6. 'Superfluidity' of light

M Wimmer (Friedrich Schiller University Jena, Germany) and his co-authors have performed an experiment [8] in which light in an optical mesh lattice had properties resembling those of superfluid liquid. The setup consisted of two fiber-optical rings about 4 km long connected through a splitter and having phase regulators responsible for nonlinearity. A slight difference in ring lengths was the reason for the occurrence in the system of a flux of discrete pulses — fluid of light. An additional pulse (phase defect) was used to excite sound waves in the 'fluid', and the velocity of these waves was measured. The frictionless motion of the phase defect confirmed the existence of 'superfluidity'. Nonlinear optical mesh lattices like those used in the experiment may be applied to examine topological effects.

7. Quantum teleportation in an optomechanical system

Experiments on quantum teleportation of photon states, spin states of atoms, and photon polarization states to vibrational states of diamond particles have been carried out. However, in the last case, the employed protocol only allowed creating a short-lived final state. N Fiaschi (Delft University of Technology, Netherlands) and his co-authors have worked out and realized in experiment a new protocol of quantum teleportation for states of an optomechanical system, providing their long lifetimes [9]. Two silica microrods cooled to the lowest levels of the vibrational spectrum were placed into two arms of an interferometer. Mechanical rod vibrations were associated with optical and microwave modes through the radiation pressure. The experiment demonstrated quantum teleportation of optical states along optical fiber from a distance of several ten meters onto the joint optomechanical state of microrods. The quantum teleportation fidelity was $(77 \pm 1)\%$. A long lifetime of a state means that the device can be regarded as quantum memory that can underlie quantum repeater nodes in a telecom network.

8. Quasi-isentropic gas compression

A unique experiment on deuterium and helium shock compression to a record pressure of 20 TPa (200 mln atm.) and a density $\rho \approx 14$ g cm^3 [10] has been performed in Russia. The experiment was carried out by a group of scientists from the Russian Federal Nuclear Center — All-Russian Research Institute of Experimental Physics (Sarov), Joint Institute for High Temperatures of RAS (Moscow), and Institute of Problems of Chemical Physics of RAS (Chernogolovka). The target was represented by two concentric steel spheres filled with deuterium or helium and surrounded by a charge of explosive substance with a mass of 85 kg in TNT equivalent. The target was transilluminated by X-rays from two betatrons that can go through objects of a thickness equivalent to 25 cm of lead. An optico-electronic detection system synchronized with the betatrons was used. Upon charge explosion, shock waves propagate inside the gas and the shell itself contracts, so that the gas moves into the state of strongly nonideal plasma with electron degeneration, and after the action of the first shock wave compression becomes approximately quasi-isoentropic. After contraction, the shell stops and then scatters. Fixed in the experiment was the shell radius dependent on time, including the instant of shutdown, when the density was maximum. As a result, the plasma compressibility (in P–ρ-coordinates) was measured. Detailed theoretical calculations have shown good agreement with the experimental data. Then the deuterium and helium dynamic compression parameters will virtually coincide, although their thermodynamic properties are different. In the investigated range of parameters, no noticeable disruptive anomalies of the type of first-order phase transitions were revealed in deuterium, as distinct from the well-known anomaly at 150–300 GPa, and no disruptive anomalies were found in helium. Thermodynamic parameters exceeding those existing in the interiors of Saturn and Jupiter were attained in the described experiment. For the equations of state of matter under extreme conditions, see [11].

9. Ultrafast copper melting

N Jourdain (University of Bordeaux, France) and their co-authors have investigated the process of ultrafast copper melting by high-power laser pulses [12]. In the interaction between a femtosecond laser pulse and a xenon target, an X-ray pulse appeared, which melted an 80-nm copper layer. Over 2000 melting acts were performed. An ultrafast transition from solid to liquid state is a nonequilibrium process, in which the electron and ion temperatures differ. This process is of importance for understanding electron dynamics under extreme heating. The measurements were taken using an X-ray absorption spectroscopy method with time resolution to fs. For a heating power from 1 to 5 MJ kg^{-1}, the melting time (violation of crystal lattice periodicity) was of the order of ps. This is less than measured earlier using electron diffraction. Measured were the copper properties near extremes of the dispersion relation $\mathrm{d}E/\mathrm{d}k = 0$ that correspond to the peaks in the X-ray absorption spectrum. The experimental results were simulated theoretically using the Bushman–Lomonosov–Fortov equation of state (for the equations of the state of matter under extreme conditions, see [13]) and the two-temperature model (electron and ion), showing good agreement with the experimental data.

10. Primordial gravitational waves

Relic radiation inhomogeneities contain information about processes in the early Universe [14]. In particular, radiation polarization may contain data on primordial gravitational waves generated presumably at the stage of cosmological inflation. P A R Ade (Cardiff University, Great Britain) and his co-authors have carried out a new analysis of the dataset of several radio telescopes that have observed relic radiation in recent years: Planck, WMAP, BICEP2,3, and the Keck Array [15], including the new data from the Keck Array at a frequency of 220 GHz and BICEP3 at a frequency of 95 GHz. Along with gravitational lensing and dust scattering, gravitational waves would contribute to the radiation polarization *B*-mode. New paper [15] reported application of the matrix method of data cleaning, which allowed measuring the *B*-mode against the background of a much stronger *E*-mode. Gravitational waves have not been found, but a new constraint, the strongest for today, on the tensor mode of perturbations (gravitational waves) $r_{0.05} < 0.036$ has been obtained with 95% fidelity. A small value of the tensor mode constrains, in turn, possible theories of inflation cosmology. Difficulties are encountered by the chaotic inflation theory predicting a large value of the tensor mode, whereas Starobinsky inflation and *k*-inflation remain unaffected by the restrictions.

11. Dust-obscured galaxies in the early Universe

Using the ALMA complex of radio telescopes located in Chili, Y Fudamoto (University of Geneva, Switzerland) and his co-authors have revealed two dust-obscured galaxies at redshifts $z = 6.68$ and $z = 7.35$, that is, in the epoch of Universe reionization — hydrogen ionization under radiation of the first galaxies and quasars [16]. ALMA first fixed two galaxies emitting high-power UV waves. Noticed close to them were additional sources of carbon emission lines and dust emission in the continuum. These sources appeared to be dust-obscured satellite galaxies. They are of interest, as they may represent a new, rather large population of galaxies in the epoch of reionization, which yield 10 to 25% of the overall star formation rate. The properties of dust in the composition of dust plasma were investigated by V E Fortov and his colleagues [17].

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