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1. Limits on spin–mass interactions

Some theories include interactions between mass and intrinsic angular momenta (spins) of objects transferred by axions or axionlike particles. A hypothetical axion field was initially proposed to explain the absence of *CP* violation in strong interactions, while its quanta, i.e., axions, can make up a significant fraction of the dark matter in the Universe. Researchers from Princeton University (USA), J Lee, A Almasi, and M Romalis, have conducted a search for interactions between mass, which consisted of two 250 kg lead bricks, and an ensemble of spin-polarized neutrons and electrons in a nearby comagnetometer. The neutron spins in ^{3}He nuclei and the electron spins in potassium nuclei gained certain polarization through collisions with ^{87}Rb atoms which had been polarized by laser light. The lead weight was set into vibration, and the corresponding periodic signal was sought in the rotation of the polarization plane of light transmitted through the comagnetometer. The spin–mass interactions might change the spin states, which could affect the signal. No such interaction was evidenced with the available exactness, and new constraints on the coupling constants were obtained in the range of axionlike particle masses of $< 10^{-6}$ eV. In the case of neutrons, these constraints are an order of magnitude better than those shown in previous laboratory experiments.

Source: *Phys. Rev. Lett.* **120** 161801 (2018)
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2. Nuclear fission reactions in a nanowire array

A Curtis (University of Colorado, USA) and his colleagues have investigated nuclear fusion reactions in hot plasma produced in the action of laser pulses on a nanowire array. A titanium-sapphire laser generated pulses 60 fs long with an energy up to 1.65 J. These pulses irradiated an ordered array of deuterated polyethylene (CD_2) nanowires 5 μm long and 0.2 to 0.4 μm in diameter. The mean density of this medium was 16–19% of the density of the matter of the nanowires themselves. Owing to the use of such an array, the laser radiation could penetrate the gaps between the nanowires, and their heating was more effective than would be possible upon pulse action on a solid surface. Quick heating induced nanowire explosions. In the plasma produced, deuterons were accelerated up to energies of several MeV and underwent thermonuclear reactions. Neutron detectors registered neutrons with energies of 2.45 MeV typical of these reactions. The neutron yield efficiency (2×10^6 per J) was a record for lasers with a pulse energy of about 1 J. It is 500 times as high as that upon irradiation of a flat CD_2 solid target, and an order of magnitude higher than in experiments with deuterium clusters. In experiments with inertial target confinement, whose aim is a liberation of thermonuclear energy, the neutron yield per J is much larger, but it needs a laser pulse energy of ∼MJ. And nanowires can constitute the basis for compact neutron sources for the materials studies.

Source: *Nature Communications* **9** 1077 (2018)
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3. Einstein-Podolsky–Rosen steering in Bose–Einstein condensates

In 1935, Erwin Schrödinger introduced the concept of Einstein-Podolsky–Rosen (EPR) steering, in which the results of measuring one part of a quantum entangled system alter the state of the other distant part and affect the results of its measurements. This steering has already been demonstrated for only pairs of particles, whereas for systems with a larger number of particles it had not been observed until it was attained for the first time by a group of researchers from the University of Basel (Switzerland) headed by P Treutlein. A cloud of ^{87}Rb atoms was confined in a magnetic trap and was transferred to the state of a Bose-Einstein condensate. After the trap potential was switched off, the cloud of atoms fell freely and expanded, and the collective spin states of different spatial parts of the condensate were registered from the resonance light absorption. The quantum inequalities were verified, which confirmed both quantum entanglement of the condensate parts and the Einstein-Podolsky-Rosen steering. The experimental methods and the effect observed may be useful for the design of new quantum sensors.

Source: *Science* **360** 409 (2018)
https://doi.org/10.1126/science.aao1850

4. Triple quantum correlations

It might be assumed that in quantum measurements with three or more possible outcomes, the quantum process of measuring is always so organized inherently that an alternative is only chosen between two outcomes of some sort, and thus all the outcomes are sorted out. So, it is hypothesized that only binary quantum correlations exist. X-M Hu (University of Science and Technology of China) and colleagues have reported the first direct experimental confirmation of the existence of correlations stronger than binary. Pairs of quantum entangled photons were produced, each of which could propagate in two different ways. In one of them, the photon could occupy one and in the other way two polarization states, so that each of the photons resided in superposition of three quantum states and was a qutrit (analogous to the qubit). The photons were sent to two laboratories, where randomly chosen measurements of photon states were carried out with three possible results. The measuring technique allowed verification of the binary correlation hypothesis formulated as inequalities analogous to Bell inequalities. These inequalities were violated at the level of 9.3σ, which rules out the presence of only binary correlations and testifies to the presence of stronger-than-binary correlations in the course of measurements.

Source: *Phys. Rev. Lett.* **120** 180402 (2018)
https://doi.org/10.1103/PhysRevLett.120.180402

5. Single photons emitted by a pair of quantum entangled atoms

R Blatt (University of Innsbruck and Institute for Quantum Optics and Quantum Information, Austria) and colleagues have demonstrated for the first time single-photon emission simultaneously by two quantum entangled atoms. The atoms were spatially separated, but jointly emitted single photons in a free space. This was possible because the atoms were connected with a common optical mode created by interferometer arms. Two $^{138}Ba^{+}$ ions were captured in a linear Paul trap and, with the help of laser pulses, were transferred to a certain superposition of excited states, so that the atoms appeared to be quantum entangled. Their emission upon transition to lower states was recorded. Single-photon emission was registered from the characteristic interference pattern, with the indistinguishability of the emitters reaching the level of 0.99 ± 0.06. The interference pattern is fairly sensitive to the degree of entanglement and to conditions near the atoms. Its distortions allowed an experimental measurement of the magnetic field gradient. Thus, this effect may turn out to be useful for the design of sensitive magnetometers.

Source: *Phys. Rev. Lett.* **120** 193603 (2018)
https://doi.org/10.1103/PhysRevLett.120.193603

6. Rhenium superconductivity in multilayer structures

D P Pappas (National Institute of Standards and Technology, USA) and his colleagues have examined superconductivity of the transition metal rhenium (Re) in multilayer metal structures. Electrodeposition was applied to place Re films inside multilayer structures of Cu, Au, and Pd films. The electrical resistance and magnetic susceptibility point to the critical temperature near $T_c = 6$ K, when the Re layer was bilaterally covered by Cu and Au layers. Analogous structures with Pd layers showed a somewhat lower T_c. For comparison, a bulk Re crystal demonstrated the maximal $T_c = 3$ K. Also revealed was a low loss level at radio frequencies for multilayers with Re deposited onto the resonators. Superconducting films with Re and Cu or Au can be integrated into standard electronic components and find practical applications.

Source: *Appl. Phys. Lett.* **112** 182601 (2018)
https://doi.org/10.1063/1.5027104

7. Quantum spin ice in $Pr_2Hf_2O_7$

In systems with interacting spins, macroscopic correlated states are possible, and are referred to as quantum spin liquids. Some evidence of their appearance has already been obtained experimentally, but no stable quantum liquids have yet been observed in three-dimensional systems. R Sibille (Paul Scherrer Institute, Switzerland) and colleagues have taken advantage of the inelastic neutron scattering technique to study $Pr_2Hf_2O_7$ crystals and found that at a temperature below 0.05 K they contain a quantum spin liquid in the form of so-called spin ice. Small dipole moments in $Pr_2Hf_2O_7$ rule out the possibility that this state constitutes a classical dipolar spin ice. An interesting feature of quantum spin ice predicted theoretically is the appearance in it of emergent electrodynamics, in which the roles of potentials and fields satisfying the Maxwell equations are played by spin correlations and quasiparticles. In particular, magnetic monopoles are possible in this 'electrodynamics'. The experiment by R Sibille and colleagues has shown the presence of a half-integral excitation continuum in $Pr_2Hf_2O_7$, which testifies to the existence of emergent electrodynamics.

Source: *Nature Physics*, online publication of April 30, 2018
https://doi.org/10.1038/s41567-018-0116-x

8. Radio wave propagation in ice

The IceCube detector located in the Antarctic ice at the South Pole has registered cosmic neutrinos with energies of up to PeV. They were detected from optical Vavilov–Cherenkov radiation of the products of neutrino interactions. It is predicted that at higher energies the most sensitive method of neutrino registering will be the Askaryan effect, i.e., coherent Vavilov–Cherenkov radiation in the radio-frequency range. In this connection, radio wave propagation in the Antarctic ice is being studied. The models of variation of ice permittivity n with depth were constructed with allowance for ice compression and density variation. The n variability must lead to the fact that the radio ray, which initially propagated at a shallow depth along the ice surface, bends downward to form a shadow zone or a 'forbidden' zone that the ray fails to reach. S W Barwick (University of California, Irvine, USA) and colleagues have measured radio wave propagation in the Antarctic ice to obtain an unexpected result: the signal was also registered in 'forbidden' zones. The mechanism of this effect remains unclear. It may be due to unaccounted microscopic radio wave scattering. This effect is of importance, because the position of signal receivers at a rather shallow depth in the shadowed region can noticeably increase the efficiency of registration of radio waves from neutrinos. For Vavilov–Cherenkov radiation and the Askaryan effect, see the paper by B M Bolotovsky in *Phys. Usp.* **52** 1099 (2009).

Source: https://arXiv.org/abs/1804.10430

9. Gravitational waves and the equation of state of neutron star matter

On October 16, 2017, the LIGO/Virgo detectors registered the gravitational wave burst GW170817, which was due to a neutron star merge. This put new restrictions on the tidal deformability of neutron stars involved in a collision event. The tidal deformability influences the approach of objects at the last stages before they merge. As a result, the form of gravitational wave signal in the case of neutron star merging somewhat differs from that observed upon the merging of two black holes. Investigating the tidal deformability, one can obtain data on the equation of state of neutron star matter. E Annala (University of Helsinki, Finland) and colleagues analyzed the GW170817 signal and derived a family of equations of state that agree with the form of the GW170817 signal and with other available data. The maximal radius R of a $1.4M_{\odot}$ neutron star was found not to exceed 13.6 km. Another group of astrophysicists from Indiana University and the University of Florida (USA) carried out a similar analysis to obtain the following constraint: $R(1.4M_{\odot}) < 13.76$ km, which is consistent with the results of the first group. The properties of nuclear matter inside a neutron star have not yet been exactly calculated theoretically, and therefore the data on neutron star merging are important for clarification. In particular, researchers are trying to find out whether so-called quark matter is present in the depths of neutron stars.

Source: *Phys. Rev. Lett.* **120** 172702, 172703 (2018)
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https://doi.org/10.1103/PhysRevLett.120.172703

10. Mercury perihelion shift

In 1915, A Einstein appealed to the General Relativity Theory to explain why Mercury's elliptic orbit rotates more quickly (by 43 arcseconds per century) than was predicted by Newtonian theory. New theoretical calculations by C Will (University of Florida, USA and Pierre and Marie Curie University, France) have shown the existence of two earlier unaccounted corrections equal to several millionths of a fraction of the main contribution comprising $43''$ per century. The first correction comes from the relativistic influence of other planets on Mercury's acceleration, and the second is associated with the interaction of Mercury's velocity and the gravimagnetic potential due to distant planets. The additional contributions found will possibly be discovered by the European–Japanese Mission BepiColombo, in the framework of which two Mercury satellites are planned to be launched at the end of 2018. BepiColombo will be able to reveal for the first time the relativistic effects associated with the influence of not only the Sun, but also of other planets, on Mercury's motion, which is of importance for verification of General Relativity and other gravitational theories. For the calculation of small corrections in General Relativity, see the book by C Will, *Theory and Experiment in Gravitational Physics* (Physics Today, 1982; Cambridge University Press, 1993) [in Russian: *Teoriya i Eksperiment v Gravitatsionnoi Fizike*. Moscow: Energoatomizdat, 1985] and also C Will's paper in *Phys. Usp.* **37** 697 (1994).

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