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1. Electron's electric dipole moment

The Standard Model of elementary particles predicts the existence of an electric dipole moment $d_e \sim 10^{-40}e$ cm of an electron, but the effects beyond the Standard Model might strengthen it by many orders of magnitude. The ACME collaboration experiments on the spectroscopic study of neutral molecular beams gave the upper bound $d_e < 9.4 \times 10^{-29}e$ cm. Researchers from the National Institute of Standards and Technology and the University of Colorado, Boulder (USA) have carried out a new precision experiment on measuring d_e using molecular $^{180}Hf^{19}F^{+}$ ions in a trap with a rotating electric field. For ≈ 700 ms, while the ions were resided in the trap, the spins of the outer electrons in the molecules precessed and the precession angle might contain a contribution from the interaction of d_e with the internal electric field of the molecule. The precession angle was measured through molecular dissociation and registration of ions. At the current precision level, no nonzero d_e was revealed, and the upper bound $d_e < 1.3 \times 10^{-28}e$ cm was obtained. Although this bound is no stronger than that obtained earlier by ACME, the work is important for the fact that the ACME result has been confirmed applying a new experimental method and another physical system. The existence of the electron's dipole moment might be due to the asymmetry under time reversal and baryon asymmetry generation in the early Universe.

Source: *Phys. Rev. Lett.* **119** 153001 (2017)
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2. Band gap control in an excitonic insulator

As was shown theoretically by L V Keldysh and Yu V Kopaev in 1964, Bose–Einstein condensation of excitons (bound states of electrons and holes) leading to the formation of a stable phase of an 'excitonic insulator' may take place in semiconductors with a narrow band gap. Later on, this phase was actually revealed in some compounds, including the layered semiconductor Ta_2NiSe_5. In their new experiment, S Mor (Fritz Haber Institute of the Max Planck Society, Germany) et al. have investigated ultrafast nonequilibrium dynamics of the Ta_2NiSe_5 electronic structure exposed to laser pulses in the near-IR range using the method of time- and angle-resolved photoelectron spectroscopy. It was established that with decreasing surface density F_c of radiation below 0.2 mJ cm^{-2} the band gap sharply narrows, while with increasing F_c it broadens out. This behavior is opposite to that typical of conventional semiconductors. To clarify the mechanism of this phenomenon, theoretical Hartree–Fock calculations were carried out to show that the key role is played here by an increase in the order parameter (density) of the excitonic condensate. For the coherent states of the excitons, see the article by L V Keldysh in the present issue of *Physics–Uspekhi*.

Source: *Phys. Rev. Lett.* **119** 086401 (2017)
https://doi.org/10.1103/PhysRevLett.119.086401

3. Ionization by phase-locked pulses

D B Foote (University of Maryland, USA) and colleagues have investigated multiphoton ionization of Xe atoms by double phase-locked laser pulses. Double pulses were obtained from single pulses using a liquid-crystal modulator or through pulse separation in an interferometer. Measurement of the number of Xe^{+} ions produced under the effect of double pulses allowed the establishment of the dependence of ionization efficiency on the shape and mutual position of pulses. In particular, even a small (about 10 %) time overlap of two pulses turned out to result in considerable changes in the ion yield due to optical interference changing the composite-pulse intensity. A small contribution from quantum interference of wave functions of excited electrons is also present. Ionization in the field of a strong electromagnetic wave was first considered in the theoretical paper by L V Keldysh in *Zh. Eksp. Teor. Fiz.* **47** 1945 (1964) [*Sov. Phys. JETP* **20** 1307 (1965)].

Source: *Phys. Rev.* A **96** 023425 (2017)
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4. Quantum-electrodynamic cascades with atom ionization

In the near future, lasers up to 10 PW in power are expected to appear, in the radiation field of which quantum-electrodynamic cascades may develop (see *Usp. Fiz. Nauk* **185** 103 (2015) [*Phys. Usp.* **58** 95 (2015)]). In such cascades, an avalanche-like chain production of photons and electron–positron pairs takes place. High-intensity laser fields are needed for $e^{+}e^{-}$ production in a vacuum, but cascades can develop in weaker fields when the sources of the initial electrons are atoms undergoing ionization. I I Artemenko and I Yu Kostyukov, researchers at the Institute of Applied Physics of RAS (Nizhny Novgorod) have studied theoretically quantum-electrodynamic cascades with heavy atom ionization in the field of two counterpropagating laser pulses. Compared to previous simplified models, ionization not only from outer but also from inner electronic levels was taken into account, and a convenient formula was obtained for the ionization rate describing both the weak intensity regime and the regime of extremely strong lasing intensity. The character of atomic ionization for different values of ionization potential and the frequency and intensity of incident radiation is determined by the Keldysh parameter γ_K. Monte Carlo simulation allowed calculating the distribution and spectrum of cascade electrons and photons. An important factor in the cascade development is the ejection of most electrons by ponderomotive forces from the region

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of the strongest laser radiation, but a small number of remaining electrons go on maintaining the cascade. The study of quantum-electrodynamic cascades is of importance for a number of promising laser technologies, including photonuclear reactions and laser–plasma particle acceleration.

Source: *Phys. Rev.* A **96** 032106 (2017)
https://doi.org/10.1103/PhysRevA.96.032106

5. Phase-free propagation in a waveguide

If the refractive index of a substance is $n \to 0$, the electromagnetic wave in the sample has a length $\lambda \to \infty$ and its phase along the entire sample remains unchanged. Phase-free wave propagation has already been demonstrated in a number of systems. To develop this technology, E Mazur (Harvard University, USA) and his colleagues created a metamaterial-based silicon waveguide which supports phase-free propagation, the new technology being compatible with conventional telecom devices. The waveguide is a plate with half-round cuts on the platform filled with an array of holes. Owing to the presence of simultaneous electric and magnetic dipole resonances, the refractive index n goes through zero at $\lambda = 1625$ nm. With n approaching zero-crossing point, the wave preserves the finite group velocity and can transfer energy. The high wave frequency hampers direct observation of its phase-free propagation, and therefore an IR camera observed beatings due to the interference of two counter-propagating waves. The beatings were coherent through the entire length of the waveguide.

Source: *ACS Photonics* **4** 2385 (2017)
https://doi.org/10.1021/acsphotonics.7b00760

6. Generation of terahertz radiation in liquid water

Electromagnetic terahertz (THz) radiation attracts much attention owing to the possibility of nondestructively radiographing many materials. One of the promising methods to generate terahertz radiation is an optico-terahertz transformation under the effect of laser light on a substance. Q Jin [University of Rochester (USA) and Huang Zhong University of Science and Technology (China)] et al. have become the first to experimentally demonstrate the generation of broadband terahertz signals from liquid water under exposure to femtosecond laser pulses with a repetition rate of 1 kHz which were focused by a parabolic mirror inside a water film ≈ 180 μm thick. The film moved at a velocity of 1.3 m s^{-1} and was held stationary between two aluminum wires owing to the water surface tension. The use of a thin film allows the radiation to go outside without being absorbed. A strong dependence of the generated radiation on the lasing polarization direction relative to the film plane and on laser pulse duration was revealed. A probable mechanism of generation deals with multiphoton and cascade ionization of molecules and plasma oscillations. For other terahertz radiation sources, see *Usp. Fiz. Nauk* **181** 867 (2011) [*Phys. Usp.* **54** 837 (2011)] and *Usp. Fiz. Nauk* **186** 667 (2016) [*Phys. Usp.* **59** 595 (2016)]. For high-sensitivity terahertz radiation receivers, see *Usp. Fiz. Nauk* **176** 983 (2006) [*Phys. Usp.* **49** 955 (2006)] and *Usp. Fiz. Nauk* **184** 1033 (2014) [*Phys. Usp.* **57** 959 (2014)].

Source: *Appl. Phys. Lett.* **111** 071103 (2017)
https://doi.org/10.1063/1.4990824

7. Water motion under lasing

Since photons transfer momenta, the effect of light on gases and liquids can induce hydrodynamic flows, which has already been demonstrated in experiment. In particular, the flow was observed near the water surface because of its deformation. Y Wang [University of Electronic Science and Technology of China and University of Houston (USA)] and colleagues have discovered a new effect when pulsed laser radiation generates steady-state flows in a pure water volume. First, the volume was filled with an aqueous suspension of gold nanoparticles, and in several minutes a hydrodynamic flow appeared in the direction of the beam. The flow was observed by the reflection of light of another laser from polymeric microspheres in the water that served as markers. The hydrophone registered the occurrence of a flow under the effect of ultrasonic waves due to a sharp thermal expansion of gold nanoparticles heated by laser pulses. It is of importance that the nanoparticles in a water bulk were only needed for the emergence of the flow, which remained after the suspension was replaced by pure water. The nanoparticles incorporated in the glass turned out to be responsible for a pure water flow. On the inner surface of the vessel, microfunnels formed by the nanoparticles were found and examined with a scanning electron microscope. The pure water flow was maintained for about an hour, while the nanoparticles were being washed out of the funnels.

Source: *Science Advances* **3** e1700555 (2017)
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8. New LIGO/Virgo results

The gravitational-wave interferometers LIGO/Virgo have registered for the first time the GW170814 gravitational burst by three detectors at once, and the GW170817 burst associated with the gamma-ray burst GRB 170817A. Along with observations of gravitational waves by two LIGO detectors located in the USA, the Virgo detector located in Italy has been used since 1 August 2017. On 14 August 2017 three detectors registered the GW170814 gravitational-wave burst. Its characteristics correspond to the merger of two black holes with masses of $30.5M_{\odot}$ and $25.3M_{\odot}$. The direction to the source is determined by an order of magnitude better with the data obtained from three detectors than from two. The gravitational wave polarization was also determined for the first time and the prediction of General Relativity concerning the tensor character of polarization was confirmed, whereas the purely scalar and purely vector versions were rejected. On 17 August 2017, the LIGO/Virgo registered the GW170817 burst, from whose localization region the GRB 170817A short gamma-ray burst was registered in 1.74 ± 0.05 s with the Fermi-GBM telescope. The masses of the merging objects range from $1.17M_{\odot}$ to $1.60M_{\odot}$, which corresponds to the neutron star masses. Thus, the merger of neutron stars in a binary system was observed for the first time with the aid of gravitational waves and it was proven that such mergers can induce short gamma-ray bursts. The velocity of gravitational-wave propagation coincided with the velocity of light with a relative precision of $\sim 10^{-15}$, which also confirms General Relativity and limits the parameters of a number of models of cosmological dark energy. Several hours after receiving the GW170817 signal, a few telescopes registered optical radiation from the same direction. The optical signal was also observed by the Russian

MASTER global robotized network of telescopes designed under the guidance of V M Lipunov (Sternberg Astronomical Institute, Lomonosov Moscow State University) (see *Usp. Fiz. Nauk* **186** 1011 (2016) [*Phys. Usp.* **59** 918 (2016)]). The optical radiation source lies in galaxy NGC 4993 at a distance of 2 kpc from its center. The radiation was also registered in the X-ray, UV, and radiofrequency ranges. The properties of the signals are quite consistent with the predictions of the 'kilonova' model. In this model, the optical radiation is due to radioactive decays of heavy nuclei produced in the course of nucleosynthesis in the merger of neutron stars. For the calculation of the generation rate of gravitational signals from the merger of neutron stars, see *Usp. Fiz. Nauk* **171** 3 (2001) [*Phys. Usp.* **44** 1 (2001)], for the history of development of gravitational wave detectors, see *Usp. Fiz. Nauk* **186** 968 (2016) [*Phys. Usp.* **59** 879 (2016)], and on the importance of gravitational-wave generation, see *Usp. Fiz. Nauk* **184** 367 (2014) [*Phys. Usp.* **57** 342 (2014)], *Usp. Fiz. Nauk* **186** 1001 (2016) [*Phys. Usp.* **59** 910 (2016)], *Usp. Fiz. Nauk* **186** 1011 (2016) [*Phys. Usp.* **59** 918 (2016)], and *Usp. Fiz. N auk* **187** 884 (2017) [*Phys. Usp.* **60** 823 (2017)].

Sources: *Phys. Rev. Lett.* **119** 141101, 161101 (2017)
Astrophys. J. Lett. **848** L12 (2017)
https://arXiv.org/abs/1709.09660
https://arXiv.org/abs/1710.05832
https://arXiv.org/abs/1709.05833
https://arXiv.org/abs/1710.05461

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