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1. Test of the equivalence principle

According to the Weak Equivalence Principle (EP), holding true within General Relativity, all bodies irrespective of their composition should fall in a gravitational field with equal accelerations, but some theories predict EP violation. Researchers from the French Aerospace Research Center ONERA and the Côte d'Azur Observatory have carried out an experiment with the MICROSCOPE satellite to test EP at the record precision level of $\sim 10^{-15}$. On board satellite are two hollow coaxial cylinders suspended freely in a gravity-free state. The inner cylinder is made of a platinum–rhodium alloy, and the outer one of a titanium–aluminum–vanadium alloy. For the purpose of control, another such system existed, but with cylinders made of the same material (Pt–Rh alloy). The forces necessary for maintaining the inner and outer cylinders motionless relative to each other were measured by electrostatic sensors. The existence of a signal modulated with a satellite orbiting frequency would testify to EP violation. No such violation has been revealed up to now, and the Eötvös parameter was limited to a value of $\delta(\mathrm{Ti},\mathrm{Pt}) = [-1 \pm 9(\mathrm{stat.}) \pm 9(\mathrm{syst.})] \times 10^{-15}$. This result improves the preceding limit by an order of magnitude. The result obtained by V B Braginsky and colleagues at Lomonosov Moscow State University had remained the best in precision (at a level of $\sim 10^{-12}$) for many years (see *Usp. Fiz. Nauk* **105** 779 (1971) [*Sov. Phys.Usp.* **14** 811 (1971)] and *Usp. Fiz. Nauk* **179** 3 (2009) [*Phys. Usp.* **52** 1 (2009)]).

Source: *Phys. Rev. Lett.* **119** 231101 (2017)
https://arXiv.org/abs/1712.01176

2. Search for axions

The axion field was initially proposed to explain the absence of *CP* violation in strong interactions, but the quanta of this field — axions — appeared to be good candidates for the role of dark matter particles. In the interaction with a coherently oscillating axion field, the electric dipole moments of nucleons will oscillate, which will affect the character of their spin precession. C Abel (University of Sussex, Great Britain) and colleagues have reported new results of the search for axions from the data of the Sussex-RAL-ILL experiment which was carried out in 1998–2002 at the Institute Laue–Langevin in France. Measured was the spin precession frequency ratio of ultracold neutrons and ^{199}Hg atoms in a trap with magnetic and electric fields. The axion field was assumed to constitute dark matter in the Galaxy, and therefore its local density and velocity are known. No anomalous precession was revealed, but bounds were obtained on the axion masses m_a and the coupling constants of the axion field with gluons and nucleons. In particular, the masses $10^{-24} \leqslant m_a \leqslant 10^{-17}$ eV were excluded. The new laboratory limits on the coupling constants are three orders of magnitude better than the astrophysical limits.

Source: *Phys. Rev.* X **7** 041034 (2017)
https://doi.org/10.1103/PhysRevX.7.041034

3. Photonuclear reactions in a lightning discharge

T Enoto (Kyoto University, Japan) and colleagues have reported the observation of gamma rays generated by photonuclear reactions and annihilation of positrons e^+ during lightning discharges. Lightning is a natural particle accelerator (see the review by A V Gurevich and K P Zybin in *Usp. Fiz. Nauk* **171** 1177 (2001) [*Phys. Usp.* **44** 1119 (2001)]). The avalanches of runaway e^- that develop in strong electric fields generate bremsstrahlung gamma-ray emission. Such gamma-ray bursts have already been registered by ground- and airplane-based detectors and have also been observed by cosmic telescopes as terrestrial gamma-ray bursts. The energy of these gamma rays has theoretically been predicted to suffice for photonuclear reaction generation in the atmosphere. Such reactions have not been observed earlier with statistical confidence, although the registration of neutrons and e^+ presumably born in these reactions has been reported. In particular, the occurrence of neutrons (n) upon the appearance of lightning was noticed at the Tyan Shan mountain station (see *Usp. Fiz. Nauk* **182** 568 (2012) [*Phys. Usp.* **55** 532 (2012)]). On 6 February 2017, T Enoto and colleagues registered at a distance of 0.5–1.7 km from a lightning discharge a gamma-ray burst less than 1 ms long simultaneously with lightning. Then, gamma-ray emission was observed, which faded out exponentially in a period of 200 ms and an additional retarding pulse with a spectral maximum at 0.511 MeV. These observations were interpreted by the following chain of events. The gamma-ray burst simultaneous with the lightning was induced by bremsstrahlung e^- emission in the discharge channel. The gamma-ray photons interacted with the air molecules with the formation of unstable ^{13}N nuclei and n in the reaction $^{14}\mathrm{N} + \gamma \to {}^{13}\mathrm{N} + \mathrm{n}$. The neutrons interacted with ^{14}N giving rise to the formation of ^{14}C and ^{15}N nuclei in an excited state, and upon their transition to the ground state gamma-ray photons with energies < 10.8 MeV were emitted and observed after the lightning. Then β^+-decays took place of ^{13}N nuclei into stable ^{13}C nuclei with the emission of e^+. The e^+e^- annihilation yielded the observed gamma-ray signal with the energy of 0.511 MeV corresponding to the e^+ mass. One minute's delay after the lightning corresponds to the direction and velocity of the wind that carried over the cloud with ^{13}N nuclei to the detectors. The described observations testify convincingly to the presence of photonuclear reactions in lightnings.

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4. Gravitational field variations during an earthquake

An earthquake induces the motion of large masses of soil, which results in gravitational field variations. As distinct from elastic P waves propagating in Earth's crust and in the upper mantle at a velocity of 6 to 10 km s^{-1}, the gravitational field perturbations move with the speed of light. M Vallee (Paris Diderot University, France) and colleagues indirectly registered these perturbations during the 2011 Tohoku (Japan) earthquake, which was 9.1 on the Richter scale. The data of 11 seismic stations located in Asia 1–2 thousand kilometers from the seismic center were used. The gravitational-field earthquake-induced perturbations produced secondary seismic waves near these stations. The gravitational and secondary seismic signals in sum caused acceleration variations of $\sim$ 1 nm s^{-2}, which were registered by the seismic stations before the primary P waves. The registration of gravitational perturbations opens a new important channel of gaining information about strong earthquakes.

Source: *Science* **358** 1164 (2017)
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5. Quasar at redshift $z = 7.54$

E Banados (Carnegie Observatory, Pasadena, USA) and colleagues have revealed a quasar at redshift $z = 7.54$, when the Universe was only 690 million years old (the previous record was $z = 7.09$). The bolometric luminosity of the quasar corresponds to the black hole (BH) mass $8 \times 10^8 M_{\odot}$. If the mass of this BH is assumed to increase constantly under accretion in the Eddington regime, then at redshift $z \sim 40$ black holes with a mass of $\geqslant 10^4 M_{\odot}$ must have existed, featuring an enigmatic origin. The peculiarities of the spectrum show that the quasar was observed when the surrounding gas was largely neutral, i.e., the reionization process has not yet finished.

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