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1. Neutrino oscillations: ν_e appearing in the ν_μ beam

The T2K (Tokai to Kamioka) experiment recorded electron neutrinos emerging in the beam of muon neutrinos. This is an indication of the reality of neutrino oscillations: $\nu_\mu \to \nu_e$. Six such candidate events have been identified, with the expected number of background events at the level of 1.5 ± 0.3. According to the T2K data, the mixing angle θ_{13} (one of the parameters characterizing oscillations) is not zero, namely, $0.03(0.04) < \sin^2(2\theta_{13}) < 0.28(0.32)$ for the direct (inverse) hierarchy of neutrino masses. The ν_μ beam was produced at the J-PARC accelerator facility in Tokai (Japan). One of the two detectors recorded the neutrinos at the base of the beam, while the second detector, which detected the appearance of ν_e in the beam, was the SuperKamiokande 22.5-kiloton Cherenkov detector located at a distance of 295 km from the accelerator. Russian scientists from the Russian Academy of Sciences (RAS) Institute of Nuclear Research participate in the T2K experiment. Electron neutrinos ν_e were also identified in the MINOS experiment conducted on the territory of the USA, in a beam of ν_μ at a confidence level of 2.7σ. According to the MINOS data, the mixing angle was bounded from above by $\sin^2(2\theta_{13}) < 0.12$; these findings are consistent with those of the T2K. For details of the long-base accelerator experiments, see a review by Yu G Kudenko in *Usp. Fiz. Nauk* **181** 569 (2011) [*Phys. Usp.* **54** 549 (2011)].

Sources: *Phys. Rev. Lett.* **107** 041801 (2011)
http://dx.doi.org/10.1103/PhysRevLett.107.041801
http://www.kek.jp/intra-e/press/2011/J-PARC_T2Kneutrino.html

2. Cooling to the quantum ground state

J D Teufel at the National Institute of Standards and Technology (NIST, USA) and his colleagues cooled a microscopic membrane to an energy below one quantum of its mechanical vibrations. An aluminium membrane consisting of $\sim 10^{12}$ atoms was placed in a superconducting microwave resonant circuit which created a strong coupling of mechanical vibrations to the electromagnetic field. After preliminary cooling with liquid helium to a temperature $T = 20$ mK, the membrane contained ≈ 30 phonons, i.e., quanta of mechanical vibrations. The resonant mechanical frequency of the membrane $\Omega_m \approx 10$ MHz was slightly lower than the electromagnetic frequency of the resonator, and for this reason microwave photons were mostly carrying energy away from the membrane; as a result, it was possible ultimately to cool it to $T = 400$ μK. This method of cooling is known as sideband cooling. An analysis of the spectra of photons emitted by the resonator established that on average the cooled membrane contained 0.34 ± 0.05 phonons, i.e., the condition $k_B T < \hbar\Omega_m$ was satisfied. Owing to the strong concentration of the electromagnetic field in the vicinity of the mechanical system, it proved possible in this experiment to achieve 10^4 times longer duration of the membrane staying in the quantum ground state than in the earlier experiment carried out in 2010 at the University of California (where a different method was used).

Source: *Nature* **475** 359 (2011)
http://dx.doi.org/10.1038/nature10261

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Translated by V I Kisin

3. Quantum superposition of frequency states of a single photon

E Zakka-Bajjani (NIST, Gaithersburg, USA) and her colleagues have obtained for the first time photons of radio emission in a quantum superposition of two states corresponding to different frequencies, or, by analogy to optics, in states of two different 'colors'. They used two harmonics of a quarter-wavelength waveguide shorted by a superconducting SQUID whose state specified the boundary conditions at the end of the waveguide. They first prepared single microwave photons in the Fock states, which were then coherently distributed between the two states having different frequencies. A superposition of these states was created by parametric frequency down-conversion: the SQUID induction was modulated at a frequency of about 7–12 GHz, equal to the difference between the frequencies of the harmonics. The photons in this experiment could have different contributions from the two frequency states, e.g., in ratios of 1:1 or 1:3. In some sense, this system resembles a pair of coupled harmonic oscillators for which the superposition of frequency states has previously been realized for ions and for a number of other quantum systems.

Source: *Nature Physics* (2011), in press
http://arXiv.org/abs/1106.2523

4. Fluorescence in clusters of nanoparticles

It is a known fact that fluorescence emission of semiconductor nanoparticles is intermittent under continuous illumination: dark and light periods last from microseconds to hours, and their distribution follows the Lévy statistics. It is assumed that the emission 'turns off' when one of the charges of the excited exciton is trapped in the surface layer or escapes from the nanoparticle. In contrast to spherical particles, elongated nanorods emit for a shorter time, since charges in them are bound less strongly. M Drndic and her research team (University of Pennsylvania, USA) discovered that, if nanorods are collected into a compact cluster, the emission from nanoparticles becomes more stable: the duration of bright periods of individual rods increases roughly in proportion to the number N of nanoparticles in the cluster; in this experiment, it was $N = 2-110$. Cadmium selenide (CdSe) nanorods ~ 5 nm in length were deposited onto a substrate and illuminated by a blue laser. Their red fluorescence was video recorded through an optical microscope, after which the lengths of dark and light time intervals were measured and recorded. The arrangement of nanorods in the clusters was mapped as a preliminary procedure using an electron microscope. One likely explanation of the dependence of the characteristics of the observed emission on N is the interaction between electrons from different nanorods. This study can help in creating fluorescent biolabels for studying processes inside cells, because the intermittency of emission from the nanoparticles is now a serious impediment to using this method.

Sources: *Nature Communications* **2** 364 (2011)
http://dx.doi.org/10.1038/ncomms1357
http://www.sciencedaily.com/releases/2011/06/110623085957.htm

5. Gravitational lensing of the cosmic microwave background

The effect of gravitational lensing of the cosmic microwave background (CMB) has been exposed at a high accuracy by means of the Atacama Cosmology Telescope (6-meter radiotelescope) located in Chile at the altitude of 5200 m above sea level. The measurements were made at a frequency of 148 GHz, and observations covered an area of the sky 324 sq. deg in total. On average, cosmic background photons were deflected by three arc minutes, so on smaller angular scales the response was somewhat smoothed. The biggest contribution to the lensing effect originated with matter density inhomogeneities at redshift $z \sim 2$ with characteristic scales of ~ 300 Mps. The gravitational lensing effect was exposed at the 4σ level as a non-Gaussian contribution to the four-point correlation function of CMB fluctuations. The background Gaussian component was calculated by randomization of the phases of the measured signal at each point. Weak indications of gravitational lensing of the CMB have previously been obtained by observing cross-correlations of the Wilkinson Microwave Anisotropy Probe and galaxy data and by measuring the attenuation of acoustic peaks. The totality of the WMAP polarization data and the Atacama Cosmology Telescope lensing data made it possible to overcome the well-known geometric degeneracy and come up with an independent confirmation, based exclusively on CMB data, of the existence in the Universe of dark energy with the equation of state $p \approx -\rho$.

Sources: *Phys. Rev. Lett.* **107** 021301, 021302 (2011)
http://arXiv.org/abs/1103.2124,
http://arXiv.org/abs/1105.041900

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