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Successful experimental verification of new uncertainty relations between error and disturbance in quantum measurement

[Abstract]

A research team led by Professor Keiichi Edamatsu, Research Institute of Electrical Communication at Tohoku University and Professor Masanao Ozawa, Graduate School of Information Science at Nagoya University has experimentally verified a violation of the Heisenberg inequality in error-disturbance uncertainly relation, a basic principle of quantum mechanics, and validated new inequalities, the Ozawa inequality and the Branciard inequality. The research team utilized a new quantum metrological method, i.e., weak measurement, to test the inequalities. The technique is expected to be important in developing novel technologies in quantum cryptography.

In quantum mechanics, it is known that there is a trade-off relation between the error of a measurement of one observable and the disturbance caused on another complementary observable, known as the error-disturbance uncertainty relation (EDR). It has long been believed that the EDR is correctly described by an inequality proposed by Heisenberg (the Heisenberg inequality). However, Ozawa showed a model that breaks the Heisenberg inequality and in 2003 revealed an alternative inequality (the Ozawa inequality) to be proven universally valid. Since 2012, a number of experimental groups including the present team have validated the Ozawa inequality by experiments using neutrons or photons.

In 2013, Branciard in Australia proposed a new inequality (the Branciard inequality), which improves but still contains the Ozawa inequality. The research team experimentally tested these inequalities making use of a new quantum metrological method, i.e., weak measurement, in photon polarization and demonstrated that the Heisenberg inequality is violated and yet the Ozawa and the Branciard inequalities hold. They also demonstrated for the first time that the measured error-disturbance relation was close to the lower bound predicted by the Branciard inequality.

The research project, aiming at the development of novel techniques in quantum

cryptography utilizing the new EDR theories, is supported by the Strategic Information and Communications R&D Promotion Program (SCOPE) from the Ministry of Internal Affairs and Communications. The present experiment clearly validated the new principal limit in physical measurement, in place of the Heisenberg inequality. The results not only demand the review of the EDR, one of the most fundamental issues in quantum mechanics, but also encourage the developments of high precision measurement techniques and quantum info-communication technologies making use of the new, universal EDR.

The research results will be published online in Physical Review Letters (American Physical Society) on December 26, 2013. The paper's title is “Experimental Test of Error-Disturbance Uncertainty Relations by Weak Measurement.”

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